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T-38C Optimal Landing Technique Determination

(Project Talon Spot)

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14. ABSTRACT
This report presents the results of the T-38C Optimal Landing Technique Determination (Project Talon Spot), an evaluation to determine the optimal T-38C landing technique. The overall test objective was to determine the optimal combination of aimpoint, glideslope and throttle modulation method to perform a safe and repeatable T-38C approach and landing within AETC requirements. The optimal combination was chosen from a selection of landing techniques consisting of an assigned aimpoint, glideslope and throttle modulation method. The optimal technique was determined from touchdown distance past threshold, touchdown speed, vertical velocity at touchdown, height over threshold and pilot comments. Testing was conducted by the USAF TPS, Class 09B. All objectives of the test were met.

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PREFACE

The Talon Spot test team would like to thank the following individuals and organizations for their invaluable contributions to the project:

Lt Dan Banakos – for your selfless dedication, your logistical talents, and the hours you spent helping our film crews capture the data.

USAF Plant 42, Palmdale Airfield Management – for all the time you spent helping us coordinate this test project and readying the runway for over 150 T-38C landings.

Ken Neitzel, Chief of Airfield Operations

Joe Kennerly, Assistant Airfield Manager

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EXECUTIVE SUMMARY

This report presents the background and results of the determination of the optimal combination of aimpoint, glideslope, and throttle modulation method for repeatable and safe T-38C landings within prescribed Air Education and Training Command (AETC) standards by the USAF Test Pilot School (TPS), 412th Test Wing (TW), AFFTC, Edwards AFB, California.

As defined in the Program Introduction Document (PID) (reference 1), this project was born from a need to reduce ambiguity within a range of instructional techniques and risk associated with trying to meet AETC performance standards for T-38C approaches and landings. When AETC transitioned from the T-38A/B to the T-38C, they incorporated C model modifications, including the addition of a Heads-Up Display (HUD) with a flight path marker (FPM) symbol, into the landing technique. To employ the new HUD in T-38 landings, AETC adopted the technique of placing the FPM over the threshold on a three degree glideslope, closely matching the landing technique used in operational fighters, but it also causing touchdowns farther down the runway and at higher speeds when compared to landings using the original references (2.5 degree glideslope aiming 500 feet short of the threshold). However, AETC chose to maintain its longstanding criteria for satisfactory landing distances. A result of the "new" glideslope and aimpoint was a greater potential for T-38 pilots to use a relatively low energy state in the critical roundout/flare/touchdown sequence in order to still land within "satisfactory" criteria while compensating for the new, longer, aimpoint (reference 2).

The flight test evaluated different combinations of glideslope (2.5 and 3.25 degrees), initial aimpoint (threshold to 500 feet short), and throttle modulation methods with the primary configuration of 60 percent flaps. Airspeed and angle of attack were maintained per the T-38C Flight Manual (reference 3). The test team identified fourteen different landing methods (a combination of aimpoint, throttle method and glideslope) encompassing the range of those used in AETC training. During "Pre-Phase A" testing, the team used the TPS flying qualities simulator and open air qualification flights to narrow down the list of potential landing methods. Six methods were evaluated during "Phase A", in which each method was flown four times for a qualitative assessment. Finally, in "Phase B", three methods were evaluated in 10 flights. These 10 flights were conducted to gain statistically significant data on touchdown parameters and to collect pilot comments and ratings on each method. Flight testing was conducted at the USAF Plant 42 in Palmdale, CA with test sorties departing from and returning to Edwards AFB.

The overall test objective was to determine the optimal combination of aimpoint, glideslope and throttle modulation method to perform a safe and repeatable T-38C approach and landing within AETC requirements. The optimal combination was chosen from a selection of landing techniques consisting of an assigned aimpoint, glideslope and throttle modulation method. The optimal landing technique was defined as that which was most repeatable, had the lowest and smoothest vertical velocity decrease in the 5 seconds prior to and at touchdown, resulted in safe threshold crossing heights, met AETC evaluation criteria, and had the most favorable pilot comments. Repeatability was determined through pilot comments on the ease of replicating their actions on a subsequent landing.

The data collected during the test could not demonstrate that the landing techniques had statistically different quantifiable features, such as touchdown speed, distance, vertical velocity on landing and threshold crossing height. Thus, pilot comments and ratings became the delineator between the techniques evaluated. The optimal landing method, of those evaluated, was flown on a 2.5 degree glideslope using the runway threshold as the aimpoint. The pilot would use the Latch to the Threshold throttle modulation method, which involved the pilot beginning throttle reduction 1000 feet short of the threshold and linearly reducing the throttle to idle in relation to the distance remaining from the threshold, arriving at idle as the aircraft crossed the threshold.

The requesting agency was Headquarters AETC/A3FV, through the USAF TPS. The responsible test organization was the 412 TW. The test was executed by four pilots and two engineers from the USAF TPS. Testing was conducted under job order number MT09B400. Testing occurred 1-26 March 2010 and consisted of 12 sorties totaling 12.8 flight hours.

All test objectives were met.

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INTRODUCTION

This Technical Information Memorandum reports on the test management project that sought to determine the optimal T-38C "Talon" landing technique of a selection of methods. The requesting agency was Headquarters AETC/A3FV, through the USAF TPS. The responsible test organization was the 412 TW. The test was executed by the USAF Test Pilot School, 412th TW, AFFTC, Edwards AFB, California. Testing was conducted under job order number MT09B400. Testing was conducted from 1 to 26 March 2010 and consisted of 12 sorties (12.8 flying hours). To meet all data analysis requirements, S/N 64-13302 and 64-13197 (Figure 1) instrumented test aircraft were flown. The USAF TPS personnel performed all testing at USAF Plant 42 in Palmdale, CA and Edwards AFB.

Figure 1 T-38C Landing at USAF Plant 42, Palmdale CA

Background

This project was born from a need to reduce ambiguity within a range of instructional techniques and risk associated with trying to meet AETC performance standards for T-38C approaches and landings (reference 1). From 2004 to 2009, in conjunction with the transition from T-38A/Bs to T-38Cs, AETC‟s documented techniques for landing the T-38 changed. The aimpoint shifted farther down the runway while criteria for touchdown speed and distance remained constant. As defined in Air Force Manual 11-251V1, T-38C Flying Fundamentals (reference 6), the new glideslope was slightly shallower (by up to ½ degree) and the aimpoint was extended five hundred feet (from the middle of the overrun to the runway threshold) in comparison to techniques used previously with the T-38A/B. Per AFMAN 11-251V1, T-38C Flying Fundamentals, the "new" glideslope and aimpoint were:

1. Glideslope: 3 degrees (Formerly 3.0 to 3.5 degrees using non-standard VASI equipment)
2. Aimpoint: Runway Threshold (Formerly 500 feet short of the threshold)

A key factor driving the changes to glideslope and aimpoint was a desire to reduce the likelihood of touchdowns short of the runway threshold, a common concern of Specialized Undergraduate Pilot Training (SUPT) instructors (references 1, 2). Another element motivating the changes was a movement within the recent AETC instructor pilot force to adjust T-38 visual references for landing such that they would mimic those used in operational fighters. T-38C modifications included the addition of a HUD, featuring a FPM symbol which provided a visual representation of the aircraft‟s flight path velocity vector. Placing the FPM over the threshold on a three degree glideslope closely matched the HUD visual references used in the F-16.

The new techniques were prone to cause landings that were longer and/or faster when compared to landings using the original references. However, AETC chose to maintain its longstanding criteria for satisfactory landings, citing safety factors related to stopping distances. Per AETC SUPT evaluation criteria (reference 4), the satisfactory criteria for normal landings were:

1. Touchdown Point: Land between 150 and 1,000 feet beyond the threshold
2. Touchdown Speed: 135 KCAS "plus fuel[1]" with a tolerance of -5 KCAS to +10 KCAS

The result of the "new" glideslope and aimpoint listed above was a greater tendency of T-38 pilots, including student pilots, to use a relatively low energy state in the critical roundout/flare/touchdown sequence in order to still land within satisfactory criteria while compensating for the new, longer aimpoint. A low energy state was a combination of relatively low speed, relatively high sink rates, higher than normal pitch attitudes and lower than normal stall margins in the flare and at touchdown, all in an attempt to decrease touchdown distance. Using a lower energy state when landing the T-38 increased the probability of a dangerous situation developing during so-called "high flares" and "balloons," which were not at all uncommon in the pilot training environment (reference 1).

Test Item Description

The T-38C aircraft was a two-seat (tandem) supersonic trainer built by the Northrop Corporation. It is powered by two General Electric J85-GE-5R afterburning turbojet engines each rated at approximately 2,900 pounds of sea level, standard day, uninstalled static thrust in full afterburner. The T-38C avionics upgrade included a HUD, two multi-function displays (MFDs), an embedded global positioning system (GPS) inertial navigation system and a radar altimeter. The test project used two instrumented test aircraft operated by the 445th Flight Test Squadron. An Aydinr Vector PCU-800 Pulse Code Modulation instrumentation system was installed in each of the instrumented test aircraft capable of recording engine parameters in addition to standard T-38C 1553 data bus information. One of the test aircraft, tail number 64-13197, had avionics upgrade program block 8 modifications that included a digital video and data transfer system, as described in its System Change Summary (reference 7). Both test aircraft were production and operationally representative for the purposes of this approach and landing test. A detailed description of the standard aircraft can be found in the T-38C flight manual (reference 3).

[1] T-38C touchdown final approach speeds are planned to be 160 knots plus one knot for every 1000 pounds of fuel in excess of 1,000 pounds, thus "plus fuel".

Test Objectives

The overall test objective was to determine the optimal combination of aimpoint, glideslope and throttle modulation method to perform a safe and repeatable T-38C approach and landing within AETC requirements. The optimal combination was chosen from a selection of landing techniques consisting of an assigned aimpoint, glideslope and throttle modulation method. The optimal landing technique was defined as that which was most repeatable, had the lowest and smoothest vertical velocity decrease in the 5 seconds prior to and at touchdown, crossed the threshold at a safe height, met AETC evaluation criteria, and had the most favorable pilot comments. Repeatability was determined through pilot comments on the ease of replicating their actions on a subsequent landing.

Specific test objectives included:

> Determine touchdown condition (distance and airspeed) and repeatability for each landing technique.
>
> Evaluate touchdown point and indicated airspeed against Air Force Instruction 11-2T-38C Volume 2 landing evaluation criteria (reference 4) and P-V4A-A T-38C Specialized Undergraduate Pilot Training syllabus landing standards (reference 5) for each landing technique.
>
> Determine the safety of each landing technique.

All test objectives were met.

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TEST AND EVALUATION

Test Execution

This section presents the results of the T-38C Optimal Landing Determination test. The optimal landing method was selected from a variety of techniques. Simulator and open air flight tests were performed in order to determine the optimal combination of aimpoint, glideslope and throttle modulation method (TMM) to perform a safe and repeatable T-38C approach and landing within AETC requirements. The optimal landing technique was defined as that which was most repeatable, had the lowest and smoothest vertical velocity decrease in the 5 seconds prior to and at touchdown, crossed the threshold at a safe height, met AETC evaluation criteria, and had the most favorable pilot comments. Repeatability was determined through pilot comments on the ease of replicating their actions on a subsequent landing. Data were collected during eight simulator sessions, four pilot checkout flights, and 12 test flights which included multiple approaches and landings at the USAF Plant 42 airport, Palmdale, CA. All landings were conducted from the front seat.

The overall test strategy was to narrow down a broad range of 14 landing techniques, defined as a combination of aimpoint, glideslope and TMM, in a methodical manner using lower fidelity methods first, namely the simulator and checkout flights. These tools would produce a set of pilot comments which would be used to eliminate eight of the techniques. This approach was problematic in that many techniques were eliminated on the basis of a relatively small number of landings and low fidelity data collection methods. The remaining six techniques would then move into Phase A of the test, where each technique would be executed four total times by two pilots to produce more pilot comments and slightly higher fidelity landing data. In addition, this phase was used to practice test procedures for Phase B. Because Phase A was primarily a handling qualities phase, the aimpoint was maintained at the threshold for all landings. The pilot comments from Phase A were used to eliminate three of the remaining techniques. The remaining three techniques then moved to Phase B, which was a combined flying qualities and performance phase. The touchdown distances from Phase A were available, if required, to adjust the aimpoint of each technique in an effort to maintain the estimated touchdown point inside the desired touchdown zone, 750 to 1000 feet from the threshold. In Phase B, the final three techniques were then flown 30 total times (split equally among four pilots), producing statistically significant landing data and more pilot comments, which was used for final analysis on each landing technique.

Test Results

Test results are separated into three topics for discussion. The first section addresses the pre-Phase A evaluations which narrowed the landing techniques from 14 to six. The TPS flying qualities simulator and open air qualification flights were used to assess various techniques qualitatively. The second section discusses the flight test-based down-selection from six to three landing techniques during Phase A. Phase A consisted of two flights, where each pilot attempted each of the six methods at least two times. Phase A data were not used to characterize touchdown distances quantitatively, but instead pilot comments were collected about which methods were easiest to fly and to explain (as if to a student) and felt the safest. The third

section discusses the results of the Phase B flight test, including pilot comments, touchdown speeds and distances, landing safety (vertical velocity at touchdown and threshold crossing height), and landing technique compliance with AETC standards. Simulated emergency landing configurations, simulated single engine and no flaps landings, were investigated on a limited basis. Results for simulated emergency landing configurations are discussed in appendix B.

Pre-Phase A—Methodology

Fourteen landing techniques were developed in support of the test. These techniques were developed by the four project pilots with over 7000 hours of combined flying experience. The pilots considered the different tasks that occurred during landing approaches and touchdowns and grouped them together in "methods" that could be taught easily to students. Prior to beginning Phase A, the list of 14 landing combinations was reduced to six so that each pilot could fly each combination at least twice during his Phase A sortie. Landing combinations were defined as a given aimpoint, glideslope, TMM and distance from the aimpoint to initiate the TMM. Prior to and during Phase A, the runway threshold was used as the aimpoint for all landings. Two glideslopes of 3.25 degrees and 2.5 degrees were chosen because of their relative difference from each other and because of HUD symbology relationships available to maintain each. Throttle modulation methods included those listed in table 1. Table 2 lists all the landing techniques evaluated during the Talon Spot test.

Table 1 Throttle Modulation Method

Crack-Pause-Pull (CPP)*	- Reduce throttles by 1/2 knob width (approximately 1 inch each) at a prescribed distance from the threshold - Pause (1/2 -1 second) and assess energy state - Reduce power to idle when pilot judges he will not land short of the runway threshold) (no later than the threshold)
Latch-to-the-Threshold (LTT)**	- Begin the throttle reduction at a prescribed distance from the threshold - Linearly reduce the throttle to idle in relation to distance remaining from the threshold - Arrive at idle as the aircraft crosses the threshold
Crack-Then-Idle (CTI)	- Reduce throttles by 1/2 knob width (approximately 1 inch each) at a prescribed distance from the threshold - Pull the throttles to idle without delay at a prescribed distance from the threshold
Pull-to-Idle (PTI)	- Pull the throttles to idle without delay at a prescribed distance from the threshold
*TMM taught in T-38A/B and mentioned in current T-38C AFMAN 11-251v1 **TMM taught to T-38C students, also included in the AFMN 11-251v1	

Table 2 Pre-Phase A Landing Techniques

Glideslope (deg)	Throttle Modulation Method	Distance from Aimpoint to Start TMM (ft)
2.5	Pull to Idle	500
3.25	Pull to Idle	500
2.5	Latch to threshold	500
3.25	Latch to threshold	500
2.5	Latch to threshold	750
3.25	Latch to threshold	750
2.5	Crack Pause Pull	750
3.25	Crack Pause Pull	750
2.5	Crack Pause Pull	1000
3.25	Crack Pause Pull	1000
2.5	Latch to threshold	1000
3.25	Latch to threshold	1000
2.5	Crack Then Idle	1250 (idle at 500)
3.25	Crack Then Idle	1250 (idle at 500)
All landing techniques used the threshold as an aimpoint and were conducted with both engines operating and 60 percent flaps.		

The TPS flying qualities simulator was used as the first means of narrowing down the list. Each landing technique was flown multiple times by each test team pilot. The aerodynamic and thrust models in the simulator were the same as the ones used in the simulators at Randolph AFB for T-38C procedures training, and the simulator included the same HUD as the T-38C. The pilot modulated power for airspeed control and used pitch to set the initial aimpoint and glideslope. During the final approach, the pilots assessed their workload to maintain airspeed, aimpoint and glideslope. Following the touchdown, the pilot assessed the safety and repeatability based on airspeed and height crossing the threshold. Sink rate in the flare and touchdown distance were measured by the simulator. While the simulator‟s fidelity was limited (no motion, limited visibility and field of regard, and inaccurate stick force model), several landing techniques were immediately highlighted as poor.

The additional training required to clear the test pilots to “crew solo” status in the T-38C afforded another opportunity to qualitatively evaluate the 14 potential landing combinations. Since none of the combinations deviated from flight manual clearances or procedures and an instructor pilot was present in the backseat, each of the four pilots was able to fly a majority of the 14 combinations during his checkout sortie. Similar to the simulator evaluation, each pilot commented on his experience. During each of these landings, the pilots focused on the general feel of the technique, noting whether they thought it was repeatable, teachable, and most importantly, safe. Although touchdown distances were estimated during these four sorties, the pilot did note techniques that yielded unusually long or short touchdown distances.

Pre-Phase A—Down-select

Of the 14 landing methods, six were chosen to move to Phase A (two sorties) as contenders for the best landing solution, shown in table 3. Criteria for down-select of these methods will be discussed in the following pages. The column entitled Brevity Title contains a shortened title which will be used to refer to each specific TMM and aimpoint combination for the remainder of this paper. While both glideslopes were relatively shallow, for brevity‟s sake the 3.25 degree glideslope was labeled the "steep" approach and the 2.5 degree glideslope was labeled the "shallow" approach. Due to the number of expected landings per sortie (12), the test team wanted to ensure both pilots could attempt each technique twice during the sortie and limited Phase A to six combinations. Although it was never the test team‟s intent to carry it into Phase B, PTI was forwarded to Phase A simply as a means to characterize the engine spool-down time. See figure A7 for a graphic of the PTI spooldown. A robotic pull-to-idle at a given distance from the aimpoint was not acceptable to AETC. However, as the least complex method in the matrix, it would provide a helpful comparison to the other techniques in the same test conditions.

Table 3 Phase A Landing Techniques

Glideslope (deg)	Throttle Modulation Method	Distance from Aimpoint to Start TMM (ft)	Brevity Title
2.5	Pull to Idle	500	PTI 500 shallow
2.5	Latch to threshold	750	LTT 750 shallow
3.25	Crack Pause Pull	750	CPP 750 steep
2.5	Crack Pause Pull	1000	CPP 1000 shallow
3.25	Crack Pause Pull	1000	CPP 1000 steep
2.5	Latch to threshold	1000	LTT 1000 shallow
All landing techniques used the threshold as an aimpoint and were conducted with both engines operating and 60 percent flaps.			

Methodology for each of these combinations is provided in detail in the "Phase A" section of this report.

The eight combinations eliminated from the matrix prior to Phase A, and the reasoning for each elimination, are detailed in the following discussion. Overall, the results from the four training flights proved more influential than the simulator results in the decisions made to narrow the list. Often, only one piece of the entire landing combination, for instance the TMM, would make the technique objectionable to the pilot, regardless of the aimpoint or glideslope. For example, each pilot felt uncomfortable with the CTI TMM, regardless of the glideslope. The CTI method was the best approximation the test team could determine to replicate the technique some current AETC instructor pilots were using to land the T-38C in the acceptable distance and airspeed zones. The method consisted of an early power reduction (250 feet prior to the 1000 feet underrun), followed by a few seconds of wind and energy assessment, and finally a pull-to-idle approximately 500 feet short of the runway threshold. If energy was assessed to be low, the pull-to-idle would be delayed. The test pilots felt the initial power reduction was unnaturally early and consistently commented after touchdown that, "there‟s no way I could explain what I just

did!" Even with extensive experience landing multiple types of aircraft, these statements spoke to the difficulty the test pilots anticipated in explaining what they did with the power and control stick to land in the zone to make the landing repeatable. Additionally, during the CTI method the test pilots perceived there was no extra energy available at touchdown to respond to events like wake turbulence or a late "go-around" call. "Perceived energy" comes in the form of power (throttle position), altitude, and lift (AOA) available at any given time. Other methods seemed to have a smoother energy bleed that was more predictable through touchdown. Both CTI combinations were eliminated based on simulator and flight results.

The CPP TMM was evaluated because of its history as a valid landing technique for over 40 years in the T-38A/B. For decades in Air Education and Training Command, the CPP throttle method was used in combination with a 3.0 to 3.5-degree glideslope and an initial aimpoint 500 feet short of the threshold. The test pilots, in general, did not like the CPP combinations due to their higher overall workloads associated with having no convenient, or less intuitive, symbology to aim at in the HUD. The angle of the glideslope itself producing an unsafe or long landing was not a concern, but instead, flying a glideslope not aligned with current HUD symbology increased pilot workload. Three of the four test team pilots learned a similar method to this early in pilot training, but with no HUD, and were comfortable forwarding three CPP combinations to Phase A. The CPP in combination with a late power "crack" at 750 feet prior to the threshold on a shallow (2.5 degree) glideslope did not differ greatly from the LTT at 750 feet. The conclusion was that waiting so late to crack the power did not allow enough assessment time ("pause") before the "pull" to see a difference from the PTI or LTT at the same distance. The technique, as a whole, increased pilot workload compared to the techniques with the shallow glideslope. Thus, the CPP at 750 feet was eliminated.

The LTT method allowed the pilot to pull the power to idle at the same perceived rate as the runway threshold approached the aircraft. The pilot would wait to start the power reduction and flare until a prescribed range (500, 750, or 1000 feet) prior to the threshold. Both steep and shallow glideslopes were attempted. The LTT at 500 feet coupled with a shallow glideslope resulted in too late of a power reduction to land in the approved zone and all landings were long. Additionally, the rate at which the aircraft had to be flared when waiting so late to reduce power was difficult to quantify and could lead to short touchdowns if misjudged. The rate at which the power was reduced when the pilots waited until 500 feet also showed no noticeable difference from the PTI at 500 feet, which was forwarded to Phase A. The LTT at 500 feet and 2.5 degrees, was eliminated.

The LTT throttle modulation method was very comfortable and repeatable for all four test pilots. The glideslope used in conjunction with the LTT method, however, made a noticeable difference in pilot workload. The T-38C HUD contained a dashed pitch line at -2.5 degrees when the landing gear was down. This provided an aiming cue for the flight path marker in order to line up for the desired glideslope. Since there was no reference pitch line for any other final approach glideslope (for example, 3.0 degrees), the pilots found the HUD symbology more of a nuisance when flying glideslopes steeper than 2.5 degrees. For this reason, the LTT at 500, 750 and 1000 feet on the 3.25 degree glideslope were eliminated. The PTI at 500 feet on the steep glideslope (3.25 degrees) was equally difficult to fly on final (due to symbology distraction),

and, as mentioned before, exhibited little or no difference in engine response from the LTT at the same distance. The PTI at 500 feet on a 3.25-degree glideslope was, therefore, eliminated.

Phase A – Test Procedures

Phase A consisted of 2 sorties (2.2 flying hours) flown by Pilot 1 and 2, as shown in table 3.

Table 4 Project Test Pilot Backgrounds

Pilot Number	Aircraft Background	Flight Hours	Phases Flown
1	F-16	1050	A (1 sortie), B (2 sorties)
2	B-52, B-2	1500	A (1 sortie), B (2 sorties)
3	F-16	1200	B (3 sorties)
4	C-17	3500	B (3 sorties)

On each of the two Phase A sorties flown, the test team flew six different combinations of glideslope and TMM which had been down-selected from the initial set of 14 landing combinations (table 3). The aimpoint was the threshold for all Phase A landings. The flight test engineer (FTE) described the upcoming landing combination (TMM and glideslope) on downwind or final, as appropriate. The pilot checked the fuel quantity, calculated an appropriate final approach speed (FAS) and configured the aircraft with gear and 60 percent flaps before beginning the final turn. The FAS could be updated during the final turn if required. The pilots found that setting a 6 to 9 degree nose low attitude around the final turn allowed them to repeatedly intercept the desired glideslope at approximately 1 nautical mile from the runway. The HUD pitch ladders and FPM were very useful in setting and holding an appropriate descent rate around the final turn.

Once established on final, the pilot maintained the desired glideslope using HUD references. For both glideslopes, the FPM was held on the threshold until the flare, except for slight movements above or below the threshold as required to correct a glideslope deviation. The shallow glideslope was maintained by aligning the FPM wings with the 2.5 degree pitch lines while maintaining the FPM over the threshold. The steep glideslope was maintained by aligning the top of the FPM "tail" with the 2.5 degree pitch lines, while maintaining the FPM over the threshold as previously described, shown in figure 2. HUD symbology for a steep approach is shown in figure 3.

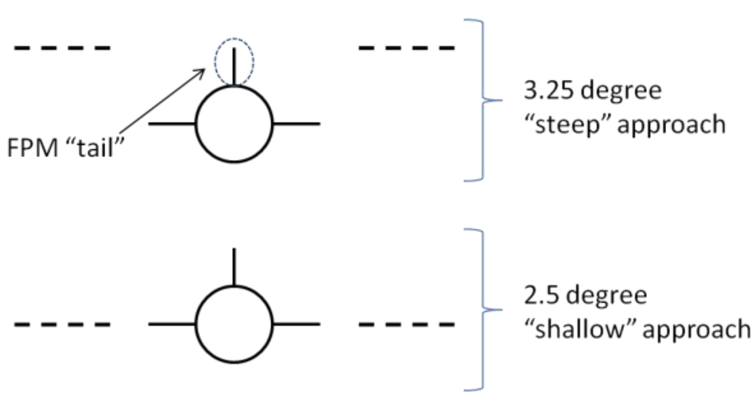

Figure 2 FPM / 2.5 Degree Pitch Ladder Alignment

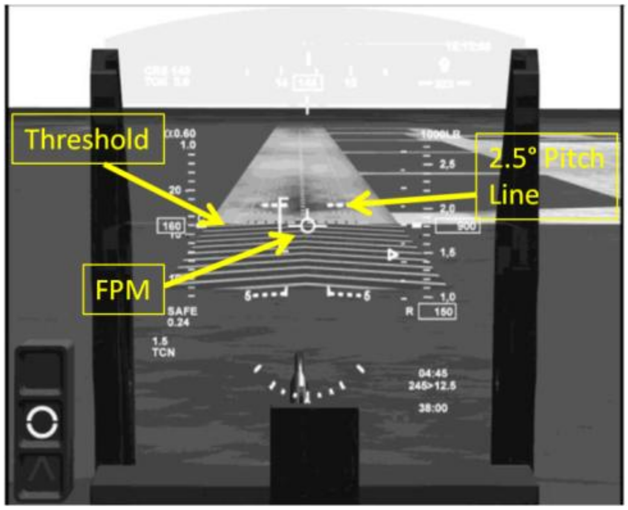

Figure 3 HUD Symbology Alignment for Steep Approach

The pilot maintained the appropriate glideslope and within ±5 KCAS of FAS until commanded to execute the landing procedure by the FTE. Three distance markers were situated on the north side of each underrun, located 500, 750 and 1000 feet from the threshold, respectively. As the aircraft approached the appropriate distance marker, the FTE would verbally command the TMM, timed to coincide with the aircraft passing the appropriate distance marker. An example of such a command was "*Ready, Ready, Latch/Crack/Pull*" depending on the type of TMM to be executed.

Although the TMM was executed at the FTE‟s command, the exact flare mechanics were left to the pilot, with the ultimate goal of arriving just above the runway surface in level flight, just above touchdown speed, followed by a smooth fully flared touchdown. Generally, the flare movement began simultaneously with the TMM. For any approach utilizing the LTT TMM, a smooth flare was started between 1000 feet and 500 feet from the threshold, with the pilot shifting his eyes to the far end of the runway and applying increasing back stick pressure to arrest the descent rate and bring the FPM to the horizon. Generally, the flare began simultaneously with the TMM. For any steep approach utilizing the CPP TMM, the descent angle was initially cut in half, followed by a smooth flare to a level attitude, using increasing back stick pressure. For a CPP executed on a shallow approach, the flare was executed as a smooth pitch change beginning at the TMM initiation, as with the LTT TMM. For any approach utilizing the PTI TMM, a smooth flare was started at 500 feet from the threshold, with the pilot shifting his eyes to the far end of the runway and applying increasing back stick pressure to arrest the descent rate and bring the FPM to the horizon.

Upon landing, the pilot would note touchdown speed from the HUD, as the FTE noted touchdown distance by referencing runway remaining markers and intermediate lights. The pilot would then execute a go-around, followed by a closed pattern. After raising the gear and flaps and climbing above 500 feet AGL, the FTE would collect pilot ratings regarding ease of execution, repeatability, workload and safety, as well as any other pilot comments about the

approach and landing. The six landing combinations were performed two times on each of the two sorties, in a random order determined prior to flight, for a total of 24 landings.

Two photo crews filmed each landing. One crew was located abeam the threshold and the other crew was located approximately 1000 feet down the runway. The camera located abeam the threshold was used to record height over threshold for each landing (appendix D). The second camera filmed the aircraft from final approach through flare and touchdown. Figure 4 below shows the location of the cameras and TMM distance markings.

Figure 4 TMM Markers and Camera Locations

The pilots rated each landing and provided comments, which were used to down-select from the six candidate landing combinations to a final set of three landing techniques, each of which was evaluated further during Phase B. Since the aimpoint could be modified in Phase B to facilitate a touchdown in the desired zone and only four landings of each type were conducted, touchdown distance performance of each technique was considered only regarding movement of the aimpoint for a given technique during the down select process.

Phase A – Glideslope Characteristics Impacting Down-Select

The pilots made several observations which were used to guide the down-select decision. The first was that the shallow glideslope approach (2.5 degrees) required less concentration and was simpler to maintain than the steep glideslope, due to the available HUD cues. The 2.5 degree pitch lines in the HUD provided a convenient approach angle cue which the pilots could use to maintain their glideslope with very little additional mental workload. Aligning the FPM wings with these lines was intuitive to both pilots. The steeper approach required slightly more concentration to maintain, as there was a less obvious cue for the pilot to follow, the top of the FPM tail aligned vertically with the 2.5 degree lines (figure 2). Overall, the available HUD cues

for each glideslope were the primary drivers of pilot workload, as opposed to the actual glideslopes themselves. No difference in workload could be attributed solely to the steepness of each glideslope.

A consequence of the shallower glideslope was the increased power setting required to maintain final approach speed. Because of the higher initial power setting, at any point in a flare from a shallow approach, the thrust available was more than at an equivalent point in a flare from a steep approach. This caused airspeed to bleed off faster and the aircraft to approach the landing speed at a higher rate during the flare from a steep approach than from a shallow approach. This reduction in power available at any given time, coupled with the slightly increased pitch change required in the flare from a steep approach possibly resulted in several relatively short, firm landings. During several flares from steep approaches, pilots perceived a "low" energy state consisting of a combination of lower than expected speed, higher than expected sink rate and lower than expected altitude. The pilots occasionally observed approach to stall indications, and at other times a more rapid than normal pitch up command was required to arrest the sink rate during the flare. All of these states were possibly caused by improper combinations of glideslope, TMM distance and TMM, creating low energy states where the pilots could not affect a normal roundout, flare and landing. In addition, due to the approach geometry, the steep approaches with TMMs at 1000 feet from the threshold resulted in a throttle reduction at nearly 60 feet in the air, a fairly uncomfortable feeling for both pilots. All pilots considered 30-40 feet an appropriate altitude for throttle reduction. As altitude decreased, larger initial power reductions were considered acceptable. Thus, TMMs where the initial throttle reduction was more than a gradual movement (ie the CPP TMM) were considered more uncomfortable than those with gradual power reductions as TMM initiation altitude incrased.

As an additional consideration, it was noted that most Instrument Landing System (ILS) approaches direct relatively shallow approach angles (approximately 2.5 degrees – 2.8 degrees). Although the touchdown point would be different between an instrument approach and a visual approach, the sight pictures and mechanics of the shallow approach were considered to closely mirror those that would result from an ILS approach, thus helping to build good habit patterns for transition to instrument flight operations. Flying a steep approach would result in a slightly different sight picture than an instrument approach, thus requiring student pilots to learn two separate techniques for application in either visual flight rules pattern operations, or instrument conditions. This was considered a disadvantage for the steep approaches.

Phase A – TMM Characteristics Impacting Down-Select

The power reduction techniques also garnered several key observations. The PTI TMM was considered by both pilots as the easiest of all three to repeatably execute, as it required no thought or modulation technique. However, from the beginning it was considered unacceptable due to AETC"s perception that it would not be accepted in a pilot training environment for fear of a student pilot executing it too early and landing short or with excessive sink rate. After using this TMM several times, the pilots noted that they sometimes landed relatively short (less than 500 feet from the threshold), with a higher speed and sink rate than desired. This was possibly related to the fact that they tended to delay their flare to coincide with their power reduction, which did not allow enough time to execute a full flare and sometimes resulted in under-flared landings.

The LTT TMM was considered a very simple technique to teach and to execute by both pilots involved in Phase A. The method was considered well suited to a more shallow, power on approach as it involved a slow reduction in power, preserving some excess thrust until crossing the threshold. In addition, because any headwind slowed the groundspeed of the approach, the pilots would reduce power at a slower rate, in proportion with the approach rate of the threshold. This naturally compensated for winds by causing the pilots to hold power in longer during approaches with higher headwinds and therefore lower ground speed. Usually, the pilots could time their throttle reduction movements to reach the idle stop within a half second or less of crossing the threshold. Since the power was retarded at a single, steady rate, the LTT TMM required less pilot workload than the CPP TMM.

The CPP TMM was a somewhat more complicated technique involving more intensive throttle movements and energy assessment by the pilot. However, the added pilot assessment of "landing assured" was considered a natural one, as this technique was taught from the beginning of pilot training. Although each pilot assessment is unique, "landing assured" is generally a state where a pilot assesses, based on groundspeed, distance to the threshold, height above the runway, airspeed, and previous experience, that he will be able to affect a safe landing, regardless of any changes that might occur in wind or engine thrust. Because each pilot made his own assessment as to when landing was assured before pulling the throttle to idle, this TMM was the least repeatable of the three techniques. Figure A7 displays a graphical representation of the three TMMs. The CPP TMM was considered less desirable for use during a shallow approach, especially when executed at 1000 feet from the threshold, because of the pilots resistance to anything but gradual power reductions while close to the underrun surface but still outside of a distance where they felt that landing was "assured".

Phase A – Aimpoint Observations

Although the aimpoint remained the threshold for both sorties, each pilot commented that he preferred aiming at the threshold during the landings. The threshold was easy to identify even from a distance, and decreased pilot workload associated with appropriately aligning the FPM, aimpoint and 2.5 degree pitch lines. In addition, using the threshold as the aimpoint was considered desirable because it was the same aimpoint used by any operational fighter a T-38 student might fly as a follow-on platform, thus providing a common landing "picture" that a student would not have to unlearn after leaving the T-38. Placing the aimpoint at the threshold was considered important for any shallow approach, due simply to the proximity to the ground during the final few seconds while approaching the runway. Based on the approaches flown, the pilots observed that moving the aimpoint into the underrun while still maintaining a 2.5 degree approach would produce a final approach that was too low to the ground at a distance too far from the threshold for the pilots comfort level. However, moving the aimpoint into the underrun was considered a more viable option for the steep approach, assuming that the TMM initiation distance was held constant. The steeper glideslope would keep the aircraft glideslope above the minimum required for pilot comfort until the flare was initiated, while the adjusted aimpoint would allow time for transition to the flare before crossing the threshold.

Phase A – Down-Select Summary

As previously noted, the PTI 500 shallow was not considered for evaluation in Phase B, as it was simply a means to characterize the engine spool-down time. Using the general observations discussed above, two of the remaining five techniques were eliminated.

Further discussion of the five remaining techniques revealed a preference for the two techniques using the LTT TMM. As stated above, the shallow power-on approach was better suited to the gradual power reduction of the LTT technique, as it maintained power throughout the approach until crossing the threshold. The LTT 750 shallow and the LTT 1000 shallow were chosen as two of the techniques to be evaluated in Phase B. In order to compare against the shallow approaches, a steep glideslope was chosen for the third landing technique, thus eliminating the CPP 1000 shallow. Of the remaining two techniques, the CPP 1000 steep was chosen over the CPP 750 steep to minimize landing distance as much as possible. In an effort to lower the uncomfortably high TMM initiation altitude associated with a steep approach aiming at the threshold, the aimpoint of the CPP 1000 steep was shifted to 500 feet short of the threshold for the final approach, while the TMM initiation distance was maintained at 1000 feet from the threshold. This decreased the initiation altitude to below 30 feet, a much more comfortable altitude for both pilots. This combination of steep glideslope, CPP TMM and a 500 feet short aimpoint was also very similar to the "legacy" method of landing the T-38A and B models, which has been taught in pilot training for decades.

These three landing techniques, LTT 750 shallow, LTT 1000 shallow and CPP 1000 steep (aimpoint 500 feet short of threshold) were considered to include a significant variation while still including those techniques preferred most by the pilots during Phase A landings. The inclusion of the modified CPP 1000 steep (with aimpoint adjusted 500 feet into the underrun) provided a chance to compare the shallow approaches with the legacy method, similar to the one currently flown by T-38A/B pilots.

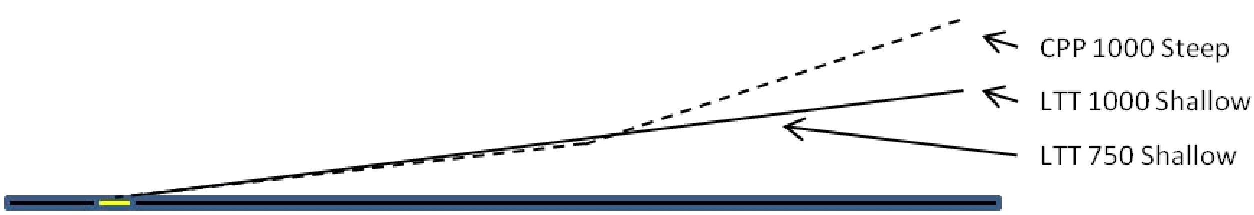

Figure 5 Phase A glideslope comparisons, expanded for clarity (not to scale)

Phase B

Three landing techniques selected during Phase A were extensively evaluated in Phase B (table 5). The threshold and a marker adjacent to the runway overrun at 500 feet from the threshold identified the aimpoints utilized.

Table 5 Phase B Landing Techniques

Aimpoint	Glideslope (deg)	Throttle Modulation Method	Distance from Threshold to Start TMM (ft)
Threshold	2.5	Latch to threshold	750
500 ft Short of Threshold	3.25	Crack-Pause-Pull	1000
Threshold	2.5	Latch to threshold	1000

For statistical purposes, the landing techniques in Phase B were randomly ordered prior to each sortie. Phase B consisted of 10 sorties (10.6 hours) with each landing technique accomplished 30 times, flown by the pilots as listed in table 5. Each landing was accomplished 30 times in order to achieve a statistical power greater than 80 percent (computed power was 81.5 percent) at a 0.05 level of significance. This two-sided t-test sample size calculation was based on an estimated standard deviation of 400 feet for each landing technique. The standard deviation, 400 feet, was used as a worst-case estimate. A minimum detectable difference of 300 feet was used in the calculation because this distance was practically significant to AETC. A difference of less than 300 feet between techniques might have been evident statistically; however this smaller delta was not meaningful to the customer.

In order to better quantify pilot comments, each landing in Phase B was followed by an in-flight survey. The pilot answered the series of questions with an ordinal rating, 1 to 5, as depicted on the scales below. The pilot also said whether the landing was safe or not safe. The pilots rated each landing in the following categories: (1) His ability to perform the TMM at the proper location without a verbal call from the flight test engineer, (2) Workload, (3) Repeatability, (4) Comfort, and (5) Safety. Histograms of the responses for all landings are in appendix A, figures A8 – A12.

Perform TMM Without Engineer Direction?

1	2	3	4	5
Very Difficult	Difficult	Average	Easy	Very Easy

Workload to maintain glideslope/aimpoint concurrently?

1	2	3	4	5
Very Difficult	Difficult	Average	Easy	Very Easy

Was the technique repeatable?

1	2	3	4	5
Not Repeatable	Difficult to Repeat	Repeatable	Easy to Repeat	Very Easy to Repeat

Was the technique comfortable?

1	2	3	4	5
Very Uncomfortable	Uncomfortable	Somewhat Comfortable	Comfortable	Very Comfortable

Was the technique safe?

1	2
Not Safe	Safe

The first question addressed how much prompting the pilot needed to initiate the TMM. As with all the responses, a 1 through 5 ordinal scale was used for the evaluation; 1 being the pilot could not anticipate the visual cues (distance to the threshold) for initial modulation of the throttle, and 5 being the pilot could fully anticipate the distance for initial throttle modulation and did not need a “ready, ready, pull/crack/latch” call from the engineer. A rating of 2 signified below average ability to discern distance to the threshold, and a rating of 4 signified above average ability to discern distance to the threshold. A rating of 3 indicated an average ability for the pilot to discern the distance to the threshold for TMM initiation. Figure A8 shows the resultant histogram, indicating that LTT 1000 Shallow had the most favorable ratings with respect to TMM execution.

For workload, the scale quantified the difficulty of concurrently maintaining both the glideslope and aimpoint required by the technique. A rating of 1 indicated that the pilot found it difficult, and a rating of 5 was given if the pilot thought it was very easy to maintain conditions for the given technique. Figure A11 depicts the workload ratings, with CPP 1000 Steep having the most unfavorable ratings.

Similarly, for repeatability and comfort, a rating of 1 was a poor rating for a technique being very uncomfortable and not repeatable, and a rating of 5 was superior for a very repeatable and very comfortable technique. A rating of 3 was an average rating for all questions and a value of

2 and 4 were necessary to describe those areas in between good, bad and average. The words to describe these ratings are listed in the scales above. The repeatability histogram is in figure A9 and shows CPP 1000 Steep with the worst ratings and LTT 1000 Shallow with the highest ratings. Figure A10 compiles the comfort ratings, where CPP 1000 Steep reflects the lowest ratings. Finally, figure A12 shows that the pilots rated every landing as safe.

Latch to Threshold

The LTT TMM was performed at 750 feet and 1000 feet from the threshold using a 2.5 degree glideslope, as described in Phase A. This technique was the most comfortable for the pilots. It required no change in attitude prior to the start of the flare. This allowed the pilot to concentrate on refinements of aimpoint and airspeed over a longer distance prior to the start of the throttle pull and subsequent flare.

The rate of aircraft movement to the threshold was predicated on ground speed which was influenced by the wind. This required the rate of throttle reduction to be changed to adjust for differing headwind component conditions. The pilots flying this maneuver found it fairly easy to judge the horizontal closure rate to the threshold and reduce the throttle at differing rates based on changing wind conditions to be in idle over the threshold. Overall, the ability to adjust the throttle reduction rate under varying conditions made the LTT technique comfortable to the pilots.

Both the 750 and 1000 foot LTT techniques were comfortable to the pilots. The 1000 foot technique was found to be more repeatable as it was easier for the pilots to accurately execute the TMM due to the discernable beginning of the underrun (1000 feet). TMM initiation at 750 feet was more difficult for pilots to accurately assess without clear markings.

Crack-Pause-Pull

The Crack-Pause-Pull throttle modulation method and landing technique required two power changes and two glideslope changes. It was accomplished in three distinct steps. The approach was established on a 3.25 degree glide slope aiming 500 feet short of the threshold. At 1000 feet short of the threshold, the pilot reduced the throttle setting by one-half knob width (approximately 1 inch), and shifted the aimpoint to the threshold. This resulted in the second glideslope, which was approximately 2.4 degrees. Then the pilot paused to assess energy state. Finally, the pilot pulled the power to idle when landing was assured (but no later than the threshold).

All four pilots considered this landing technique the least comfortable method of the three investigated in Phase B. Three deficiencies were repeatedly noted by the project test pilots. The CPP was more complicated by design and difficult to repeat precisely. The technique often led to low threshold crossing heights, which in turn led to “aft stick pumps” in the flare causing ballooning (figure A5). The vertical velocity trace during the last 5 seconds of flight, prior to touchdown, of a CPP landing is compared to an LTT landing in figure A6.

The CPP method had one clearly defined action point, which was the crack in power 1000 feet prior to the threshold. The length of pause and how quickly to pull the throttles to idle were left to pilot discretion. Therefore, the technique was less repeatable from approach to approach.

Another factor that compounded the variation among CPP approaches was the lack of a HUD reference line for a 3.25 degree glide slope. Also, there was no HUD pitch reference after the aimpoint shift. Throughout the landing test four CPP approaches were repeated because of pilot error during the aimpoint shift or flare. None of the other approach techniques required repeating, which was evidence that the increased complexity of this technique made it more difficult to accomplish as precisely as the two other landing methods.

Although the CPP approach was flown on a 3.25 degree glide slope, aiming 500 feet short of the threshold resulted in a shallower short final approach than the other methods tested. One of the justifications given to the test team by AETC for flying the more complicated procedure was to improve back seat visibility during no-flap approaches (reference 1). The trade-off for more visibility during the approach was negated by less ability to see over the nose as the aircraft transitioned to a shallower approach after the aimpoint shift. The rapid changes in end-game glideslope gave the pilots a very short time to assess whether they would pass safely over the threshold. This sometimes resulted in errors in pilot assessment of their approaching height over threshold. Aft stick pumps, or rapid aft stick deflections, were common just prior to crossing the threshold in response to the pilots" reaction to a perceived impending touchdown in the underrun. Short-term increases in altitude, or balloons, were more common with this landing technique than the other two.

Due to the CPP method having two pitch changes, in both the aimpoint shift and flare, there were two opportunities to underestimate the extra pull required. Too little pull at the aimpoint shift resulted in a shallower than desired approach and increased the probability of an underrun landing. The chances of landing short of the threshold were compounded by the second pull to flare, which also occurred prior to the threshold.

Landing Touchdown Distance, Speed and Compliance with AETC Requirements

The landing touchdown speed delta from desired touchdown speed was recorded to calculate the mean touchdown speed and standard deviation for each Phase B landing technique and determine compliance with AETC requirements. Conditions for each landing are listed in appendix F, table 12. Per the SUPT syllabus (P-V4A-A):

Main wheels touchdown: -5 to +10 knots of desired touchdown speed.

The desired touchdown speed was calculated in accordance with flight manual guidance, and it varied based on fuel remaining on final. The mean and standard deviation of landing speed deltas for all three techniques was within AETC requirements (table 6). Statistical testing (f-tests) were performed to determine if the speeds of the three landing techniques had equal variances. The f-test revealed that CPP 1000 steep and LTT 1000 shallow had equal variances, but LTT 750 Shallow had a greater variance. CPP 1000 steep and LTT 1000 shallow were found to have equal variances, while LTT 750 Shallow had a greater variance. A two sample t-test assuming equal variances was performed to determine if landing technique had an effect on the mean landing speed when comparing CPP 1000 steep to LTT 1000 shallow. The mean landing speeds were statistically equal, with $t(29)=2.00$, two-tail $p=0.31$. Two sample t-tests, assuming unequal variances, were performed to determine if landing technique had an effect on the mean landing speed when comparing CPP 1000 steep with LTT 750 shallow and LTT 1000 shallow with LTT 750 shallow. When comparing CPP 1000 steep to LTT 750 shallow, $t(29)=2.00$ and

two-tail $p=0.45$. When comparing LTT 1000 shallow to LTT 750 shallow, $t(29)=2.01$ and two-tail $p=0.91$. The statistical analysis could not show that the mean touchdown speeds of the three techniques were different.

Table 6 Landing Touchdown Speed Delta

Landing Technique	Touchdown Speed Delta* (KCAS)
Latch to the Threshold at 1000" Aim at Threshold 2.5° Glideslope	Mean: 2.2 Std Dev: 3.7 95% CI: ±1.4
Crack Pause Pull at 1000" Aim 500" Short 3.25° Glideslope	Mean: 1.1 Std Dev: 4.1 95% CI: ± 1.5
Latch to the Threshold at 750" Aim at Threshold 2.5° Glideslope	Mean: 1.9 Std Dev: 5.1 95% CI: ± 1.9
* Speed delta between touchdown speed and calculated touchdown speed AETC Requirement: Main wheels touchdown: -5 to +10 knots of desired touchdown speed	

The landing touchdown distance past the runway threshold was recorded to calculate the mean touchdown distance and standard deviation for each Phase B landing technique and to determine if the touchdown distances complied with AETC requirements. AETC requirements, per the SUPT syllabus (P-V4A-A) and Aircrew Evaluation Criteria (Air Force Instruction 11-2T-38CV2) Standard Qualification (Q-1) were:

Touchdown point: 150 feet to 1,000 feet from the runway threshold.

The touchdown distance for each landing was determined via two methods. IRIG time was recorded on the data acquisition system (DAS) when the main wheels touched down, and the latitude and longitude coordinates at that time were identified via a handheld Wide Area Augmentation System enabled GPS, which provided approximately 70 foot accuracy. The distance between the touchdown coordinates and the coordinates of the center of the runway threshold were used as touchdown distance. In case of GPS signal loss or DAS error (one of which occurred on approximately half the landings), the flight test engineer in the rear cockpit would note where the main wheels touched down with respect to the runways lights, which were spaced every 200 feet after the threshold. This technique's estimated resolution was within 100 feet. Flight test landing touchdown distances were then corrected for winds via the following equation (reference 8). Wind corrections were applicable to all three techniques after crossing the threshold at idle power.

$$S_{A_{NW}} = \left(1 + \frac{V_W}{V_{A_g}}\right) S_{A_T}$$

where:

S_{ANW} = landing touchdown distance with no wind (ft past threshold)

S_{AT} = landing touchdown distance observed (ft past threshold)

V_W = wind speed (kt)

V_{Ag} = aircraft ground speed (kt)

Since the aircraft could have touched down up to 10 knots fast and stayed within the AETC required touchdown speed range, the distance past the threshold where the aircraft was at touchdown speed plus 10 knots was also determined. That distance was found by identifying, via GPS coordinates, the location of the aircraft when it was at touchdown speed plus 10 knots. The distance past the threshold was determined by finding the delta between those GPS coordinates and the coordinates of the runway threshold. Finally, when the aircraft touched down faster than the computed touchdown speed, the deceleration over the last two seconds was computed and used to determine where the aircraft would have touched down had the pilot held it off in the flare until reaching the calculated touchdown speed. Table 7 shows the results of the touchdown distance investigation including means, standard deviations (std dev), and 95 percent confidence intervals (95 percent confidence interval (CI)) in the mean.

Table 7 Landing Touchdown Distance

Landing Technique	**Mean Distance and Standard Deviation* (ft)**			
	Flight Test Data	**Wind Corrected**	**Distance at TD Speed + 10 KCAS****	**Projected Distance at TD Speed*****
Latch to the Threshold at 1000‟ Aim at Threshold 2.5° Glideslope	Mean: 952 Std Dev: 403 95% CI: ±149	Mean: 976 Std Dev: 417 ****CI 95% CI: ±148	Mean: 326	Mean: 1126 Std Dev: 381 95% CI: ±147
Crack Pause Pull at 1000‟ Aim 500‟ Short 3.25° Glideslope	Mean: 992 Std Dev: 449 95% CI: ±152	Mean: 997 Std Dev: 399 95% CI: ±157	Mean: 400	Mean: 1191 Std Dev: 396 95% CI: ±144
Latch to the Threshold at 750‟ Aim at Threshold 2.5° Glideslope	Mean: 847 Std Dev: 387 95% CI: ±143	Mean: 865 Std Dev: 395 95% CI: ±146	Mean: 294	Mean: 1181 Std Dev: 426 95% CI: ±158

* Distance represents feet past the runway threshold where the main wheels touched down.
** Distance where the T-38C would have touched down 10 knots fast of calculated touchdown speed.
*** Distance where the T-38C was projected to touch down at the calculated touchdown speed.
****Confidence interval in the mean
AETC Requirement: Touchdown point: 150 feet to 1,000 feet from the runway threshold

F-tests were performed to determine whether the three landing techniques had statistically equal variances for wind corrected touchdown distances. The only two techniques which had statistically different variances were the CPP 1000 Steep and the LTT 1000 Shallow. Therefore, a two sample t-test assuming unequal variances was performed to determine if the landing technique had an effect on the mean landing distance when comparing the CPP 1000 Steep and LTT 1000 Shallow techniques. The mean landing distances were determined to be statistically equal, with $t(29)=0.20$, two-tail $p = 0.84$. Two sample t-tests, assuming equal variances, were then performed to determine if landing technique had an effect on the mean landing distance when comparing CPP 1000 Steep with LTT 750 Shallow and LTT 1000 Shallow with LTT 750 Shallow. When comparing CPP 1000 Steep to LTT 750 Shallow, $t(29)=1.25$ and two-tail $p=0.22$. When comparing LTT 1000 Shallow to LTT 750 Shallow, $t(29)=1.03$ and two-tail $p=0.31$. The statistical analysis could not show that the three techniques‟ mean touchdown distances were different.

While all of the wind corrected landing distance means fell within AETC standards, 40 percent of landings for each technique failed AETC standards. For all landing techniques, the 95 percent confidence interval upper bound exceeded the 1000 feet maximum touchdown distance allowed by AETC. Had the aircraft landed at the beginning of its airspeed window (calculated

touchdown speed plus 10 knots), the data suggest that the mean of those landings would have been well within AETC standards (figure A2). Since the landing techniques resulted in consistently fast landings (table 7), the projected distances at calculated touchdown speed were calculated and were all within 200 feet of AETC requirements. Figure A1 in appendix A shows the maximum and minimum landing distances along with the means and standard deviations. This supports pilot comments that the CPP technique was more prone to exceptionally long or short landings (from 100 to 2200 feet past the runway threshold), as it reflects the greatest maximum and minimum touchdown distances. This reflects the tendency for some pilots to balloon a CPP landing, as discussed above. Landing technique had no significant effect on landing touchdown distance, and none of the techniques offered 95 percent confidence intervals for touchdown distance within AETC criteria. A way to consistently land in the AETC approved touchdown zone using one of the techniques evaluated would be to land fast but still within AETC touchdown speed requirements. Touchdown airspeeds were governed by the flight manual (reference 3), while touchdown distances were governed only by AETC.

A relationship (linear correlation coefficient of 0.4) was identified between landing touchdown distance and speed (figure A3). When landing fast, pilots tended to touch down closer to the threshold. When the pilot landed slower than the computed touchdown speed, touchdown distances were further from the threshold.

Flight test data may be skewed to display longer than representative landing distances due to the fuel weights at which many of the landings were accomplished. Of 101 total (non-simulated emergency) landings accomplished, over a third (37) were accomplished with more than 3000 pounds of fuel remaining, termed “heavy” landings. However, landing with greater than 3000 pounds of fuel is a very rare occurrence in a pilot training environment. Most pilot training landings occur near the end of a mission (usually below 2500 pounds of fuel remaining) after landing weights and thus final approach speeds have been significantly reduced. To investigate the impact that the significant number of “heavy” landings might have had on the results, the LTT 1000 Shallow landing distances were compared, differentiated by fuel weights. Thirty-five LTT 1000 Shallow landings were accomplished during the test, representing the thirty landings evaluated in the preceding statistical analysis and five additional landings. The average of all 35 landings, with fuel weights ranging from 4000 pounds to 1500 pounds, was 1000 feet (standard deviation of 398 feet), while the average for landings with fuel weights above 3000 pounds (average fuel weight of 3400 pounds) was 1269 feet (standard deviation of 348 feet). The average for landings with fuel weights at or below 3000 pounds (average fuel weight of 2300 pounds) was 820 feet (standard deviation of 325 feet). A statistical f-test was performed on the data. This test was designed to accept or reject the assumption that light weight landings ($\leq$3000 pounds of fuel) versus heavy weight landings ($>$ 3000 pounds of fuel) would have statistically equal variances for wind corrected touchdown distances. A two sample t-test, assuming unequal variances and unequal sample sizes with α=0.05, was performed to determine if fuel weight had an effect on the mean landing distance. Twenty-one light weight and 14 heavy weight LTT 1000 Shallow landings were accomplished. When comparing light (2333 lb average fuel weight) to heavy weight (3443 lb average fuel weight) LTT 1000 Shallow landings, two-tail p=0.0006, thus rejecting the assumption that the mean heavy and light weight landing distances were statistically equal. It can be surmised that heavier fuel loads, and therefore higher final approach speeds, had

a impact on landing distances in the LTT 1000 shallow approaches, causing them to be longer than they would have been if all the landings has been performed with lower, more operationally representative fuel weights. As stated previously, the LTT 750 Shallow approaches did not have enough landings at lower fuel weights to allow this type of analysis, however it is suspected that the result would be the same if more low fuel weight landings had been accomplished. A chart depicting this correlation is in figure A13.

This type of comparison was also conducted for the CPP 1000 steep landings. Thirty-five CPP 1000 Steep landings were accomplished during the test, representing the thirty landings evaluated in the preceding statistical analysis and five additional landings. The average of all 35 landings, with fuel weights ranging from 4000 pounds to 1600 pounds, was 935 feet (standard deviation of 422 feet), while the average for landings with fuel weights above 3000 pounds (average fuel weight of 3300 pounds) was 1182 feet (standard deviation of 518 feet). The average for landings with fuel weights at or below 3000 pounds (average fuel weight of 2500 pounds) was 821 feet (standard deviation of 422 feet). To determine if fuel weight had a statistically significant effect on landing distance for CPP 1000 Steep landings, a statistical f-test was performed. This test demonstrated that landing light weight ($\leq$3000 pounds of fuel) versus heavy weight (>3000 pounds of fuel) did not have statistically equal variances for wind corrected touchdown distances. A two sample t-test, assuming unequal variances and unequal sample sizes with $\alpha=0.05$, was performed to determine if fuel weight had an effect on the mean landing distance. Twenty-four light weight and 11 heavy weight CPP 1000 Steep landings were accomplished. When comparing light to heavy weight CPP 1000 Steep landings, two-tail $p=0.008$, thus rejecting the assumption that the mean heavy and light weight landing distances were equal. As with the LTT 1000 shallow landings, this result demonstrated that heavier fuel loads and therefore higher final approach speeds had a statistically significant impact on landing distances in the CPP 1000 Steep approaches. The landing means were significantly longer than they would have been if all the landings has been performed with lower, more operationally representative fuel weights.

It was shown that the heavy fuel weight of many landings (above 3000 pounds of fuel) significantly increased the landing distance, thus increasing the overall average of the LTT 1000 Shallow landing technique results. These data suggest that if landings had been limited to a lower fuel weight, the resulting landing distances would have been significantly lower. If executed in an operational setting, where light weight landings are prevalent, landings using both the CPP 1000 Steep and the LTT 1000 Shallow technique would demonstrate statistically significant shorter landing distances than those observed in this test. A graphical representation of this relationship between fuel weight and landing distance is shown in figure A14.

Landing Safety
Results for determining the landing safety are broken into two areas; vertical velocity at touchdown, and height above threshold, and are detailed below. Also recorded was the vertical velocity 5 seconds prior to touchdown to observe the flight path characteristics associated with each of the landing techniques. A summary of the vertical velocity at touchdown data is shown below in table 8.

Table 8 Landing Vertical Velocity

Landing Technique	Vertical Velocity at Touchdown		
	Vertical Velocity (ft/min)	**Percent Allowable (%)**	**Vertical Velocity in last 5 seconds (ft/min)**
Latch to the Threshold at 1000" Aim at Threshold 2.5° Glideslope	Mean: -86 Std Dev: 48 Max: -176	24.56%	Mean: -234 Std Dev: 124 Max: -510
Crack Pause Pull at 1000" Aim 500" Short 3.25° Glideslope	Mean: -86 Std Dev: 52 Max: -189	24.82%	Mean: -143 Std Dev: 116 Max: -455
Latch to the Threshold at 750" Aim at Threshold 2.5° Glideslope	Mean: -83 Std Dev: 72 Max: -289	23.59%	Mean: -233 Std Dev: 131 Max: -456
* Percent allowable is based on worst case allowable requirement: 340 ft/min vertical velocity, full fuel (>1700 pounds), normal landing (no crab)			

The mean vertical velocity for all landing techniques was within the flight manual allowable vertical velocity limits. The sample means and standard deviations indicated that there was no statistical difference between the landing techniques in terms of vertical velocity. The maximum vertical velocity experienced for each landing technique is also shown, which indicated that all landing techniques fell within the allowable limits for a normal, full fuel landing (greater than 1700 pounds fuel).

A sample of landings were performed in the full fuel (greater than 1700 pounds) category, however no landings resulted in a vertical velocity at touchdown exceeding the lighter weight category restriction of 340 feet per minute. The mean vertical velocity for the last 5 seconds before touchdown was lowest for the “crack pause pull” technique, which corresponds with the lower average height above threshold shown below. Although statistically there were no differences between the tested landing techniques for vertical velocity at touchdown, the flare induced by the crack pause pull technique often resulted in a slightly lower threshold crossing height and hence a lower vertical velocity prior to the threshold.

Figure 6 Threshold Crossing Height Measurement Calibration

The height above the threshold was also an indication of a safe landing technique. Threshold crossing height was determined by measuring the distance between the base of the main landing gear of the T-38 and the threshold paint marker. As shown above in figure 6, the camera was in a fixed position and was calibrated using the marker pole, with alternating colors painted every foot of distance of the pole for easy visual references. Post test analysis was performed to measure each landing height against the calibration photo height with the use of grease pencils.

AETC‟s recommended threshold crossing height for landing approximately 1000 feet beyond the threshold was between five and ten feet (reference 6). The summarized data are shown below, and the detailed list of all landing height above threshold values is in appendix A.

Table 9 Landing Height Above Threshold

Landing Technique	**Mean Height Above Threshold and Standard Deviation (ft)**
	Height Above Threshold (ft)
Latch to the Threshold at 1000‟ Aim at Threshold 2.5° Glideslope	Mean: 4.34 Std Dev: 2.11
Crack Pause Pull at 1000‟ Aim 500‟ Short 3.25° Glideslope	Mean: 2.42 Std Dev: 1.28
Latch to the Threshold at 750‟ Aim at Threshold 2.5° Glideslope	Mean: 3.23 Std Dev: 2.03

Within one standard deviation, the mean threshold crossing heights of all three landing techniques did not distinguish any technique as being safer than another. Although the AFMAN 251 safe threshold crossing height recommendation is between five and ten feet, Talon Spot test pilots experienced safe landings for each of the three techniques even though the average was slightly lower (averages listed above) than the AFMAN recommendation. To further expand on the term “safe,” the pilots commented that in all cases sink rates could be arrested and they could make required control movements to land on the runway without any threat of injury to the landing gear or personnel.

Additionally, of note, threshold crossing height requirements were dependent on where the desired aircraft landing distance was set. The threshold crossing height recommendation from AFMAN 11-251 assumes a landing within the desirable/acceptable landing distance of 750 feet plus or minus 250 feet. With the given requirements to not adjust the acceptable landing distance currently used for AETC T-38 training, results from the Talon Spot testing suggest that with each of the techniques, even with slightly lower threshold crossing heights, still resulted in what the pilots determined to be safe landings.

Although all techniques landed on average slightly lower than the suggested AFMAN 11-251 safe threshold crossing height, pilot comments for every landing in Phase B regarded all three techniques as safe (figure A12).

Test Results Summary

The overall test objective was to determine the optimal combination of aimpoint, glideslope and throttle modulation method to perform a safe and repeatable T-38C approach and landing within AETC requirements. The optimal combination was chosen from a selection of landing techniques consisting of an assigned aimpoint, glideslope and throttle modulation method. The optimal landing technique was defined as that which was most repeatable, had the lowest and smoothest vertical velocity decrease in the 5 seconds prior to and at touchdown, crossed the threshold at a safe height, met AETC evaluation criteria, and had the most favorable pilot comments. Repeatability was determined through pilot comments on the ease of replicating their actions on a subsequent landing.

Specific test objectives included:

> Determine touchdown condition (distance and airspeed) and repeatability for each landing technique.
>
> Evaluate touchdown point and indicated airspeed against Air Force Instruction 11-2T-38C Volume 2 landing evaluation criteria (reference 4) and P-V4A-A T-38C Specialized Undergraduate Pilot Training syllabus landing standards (reference 5) for each landing technique.
>
> Determine the safety of each landing technique.

All test objectives were met.

The most promising three landing techniques, CPP 1000 steep, LTT 1000 shallow and LTT 750 shallow, were accomplished thirty times each during Phase B flight testing. All three of these landing techniques had statistically equal touchdown speed and distance means.

The landing touchdown speed means, one standard deviations and 95 percent confidence intervals were all within the AETC landing touchdown speed requirement. The landing touchdown distance means were all within the AETC landing touchdown. However, the positive bounds of the one standard deviations and 95 percent confidence intervals put the touchdown point beyond the upper limit that AETC would accept for both flight test data, wind corrected flight test data and projected „on speed touchdown" distances. Had the pilots landed 10 knots fast, within AETC speed requirements, they would have landed within AETC distance requirements as well. A way to consistently land in the AETC approved touchdown zone using one of the techniques evaluated would be to land fast (but still within AETC touchdown speed requirements). However, data acquired during this test is skew towards heavy weight landings. Analysis has shown that if executed in an operational setting, where light weight landings are prevalent, landings using the LTT 1000 Shallow technique would demonstrate statistically significant shorter landing distances than those observed in this test.

All three landing techniques were considered safe, as a function of their vertical velocity at touchdown and the height at which they cross the threshold. Quantitative, statistically significant differences between the safety of the three techniques could not be demonstrated.

Since quantitative results did not reveal discriminators between the landing techniques, pilot comments played a crucial role in the quest for the safest, most teachable and repeatable landing technique within AETC standards. These comments were also substantiated with ordinal-response questionnaires which promoted LTT 1000 Shallow as the most repeatable and CPP 1000 Steep as the least comfortable technique with the highest workload.

The CPP TMM had a higher workload, as it involved a more complicated throttle movement and energy assessment by the pilot. The CPP technique also resulted in what the pilots considered an uncomfortably low threshold crossing height, often resulting in a ballooning motion immediately prior to touchdown.

The LTT Shallow technique was the most comfortable for the pilots. Both the 750 and 1000 foot techniques were comfortable to the pilots, but the 1000 foot technique was more repeatable as it was easy for the pilots to accurately execute their TMM as they crossed the beginning of the underrun (1000 feet short of the threshold). The LTT 750 shallow technique increased pilot workload slightly as it forced them to discern the location of 750 feet short of the threshold underrun.

Since the landing conditions of all three landing techniques were indistinguishable and all three were considered safe, pilot comments drove the overall determination of optimal landing technique, of those methods evaluated. With 60 percent flaps, the optimal landing method, of those evaluated, was flown on a 2.5 degree glideslope using the runway threshold as the aimpoint. The pilot would use the Latch to the Threshold throttle modulation method, which involved the pilot beginning throttle reduction 1000 feet short of the threshold and linearly reducing the throttle to idle in relation to the distance remaining from the threshold, arriving at idle as the aircraft crossed the threshold.

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4. *T-38 Aircrew Evaluation Criteria,* Air Force Instruction 11-2T-38, Volume 2, HQ AETC/A3FV, 27 April 2009.

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7. *Block 8 Air Vehicle System Change Summary*, The Boeing Company, St. Louis, Missouri, July 2009.

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APPENDIX A - FIGURES

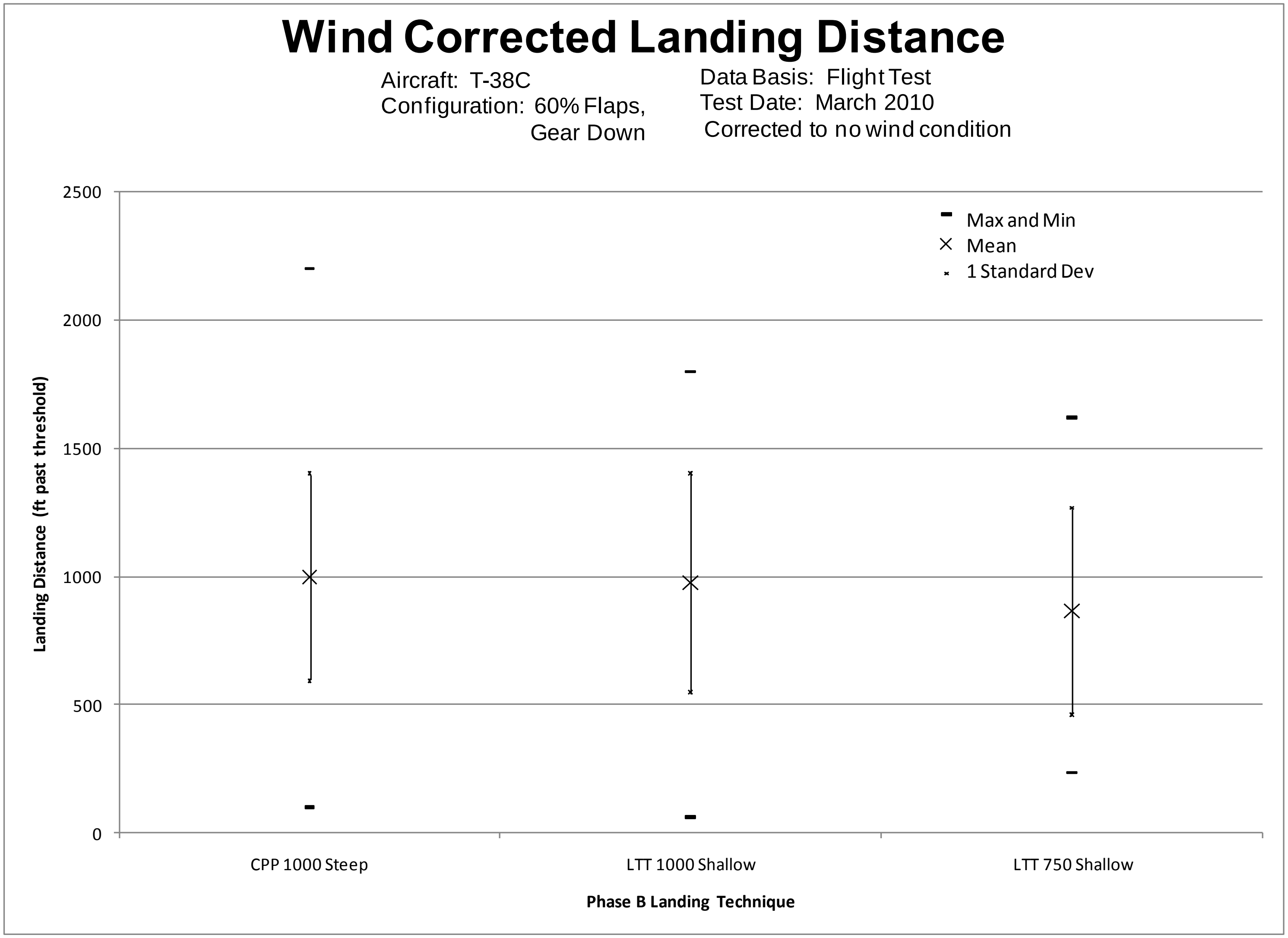

Figure A1 Wind Corrected Landing Distances

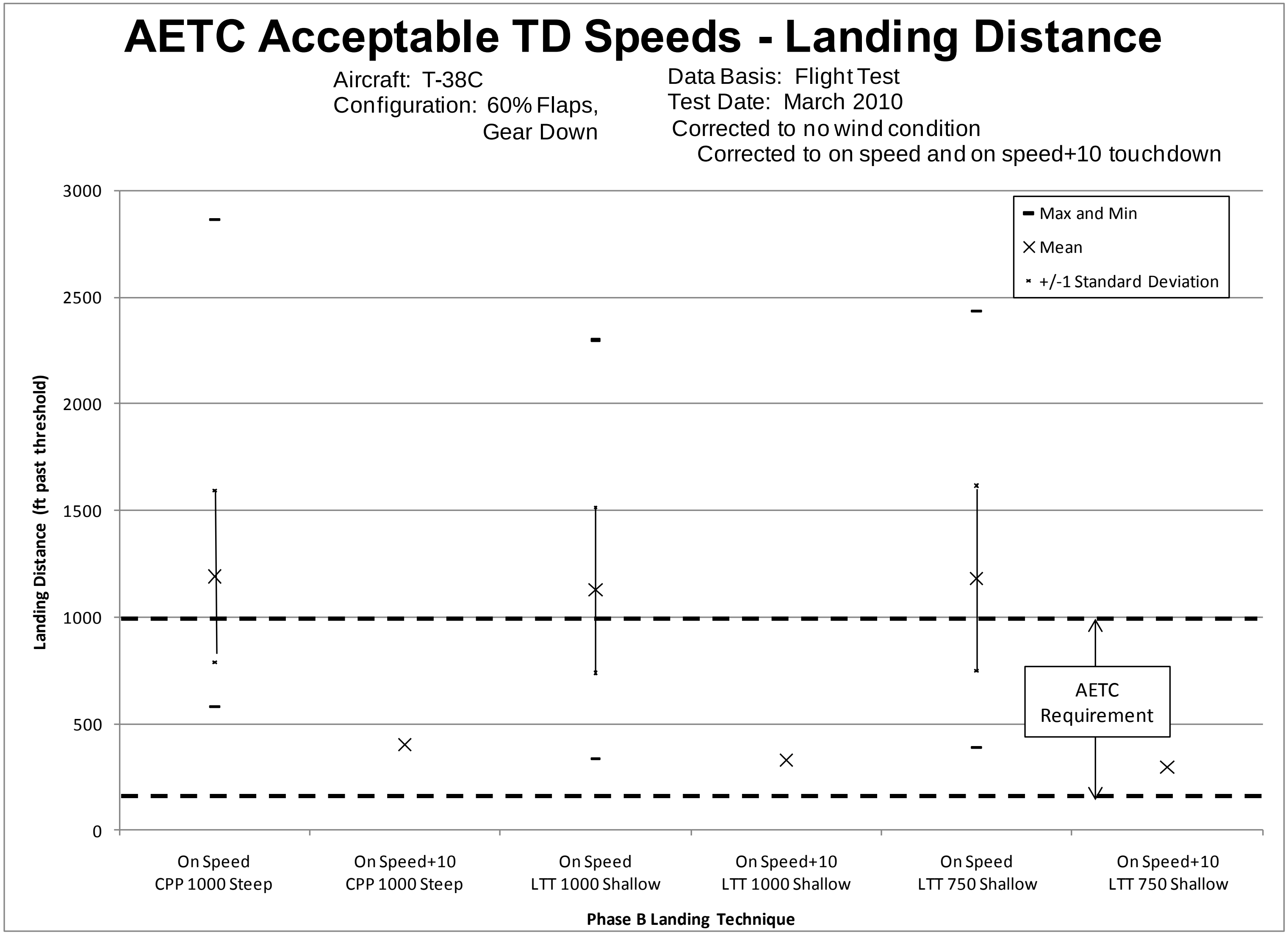

Figure A2 Landing Distances within AETC Acceptable TD Speed Range

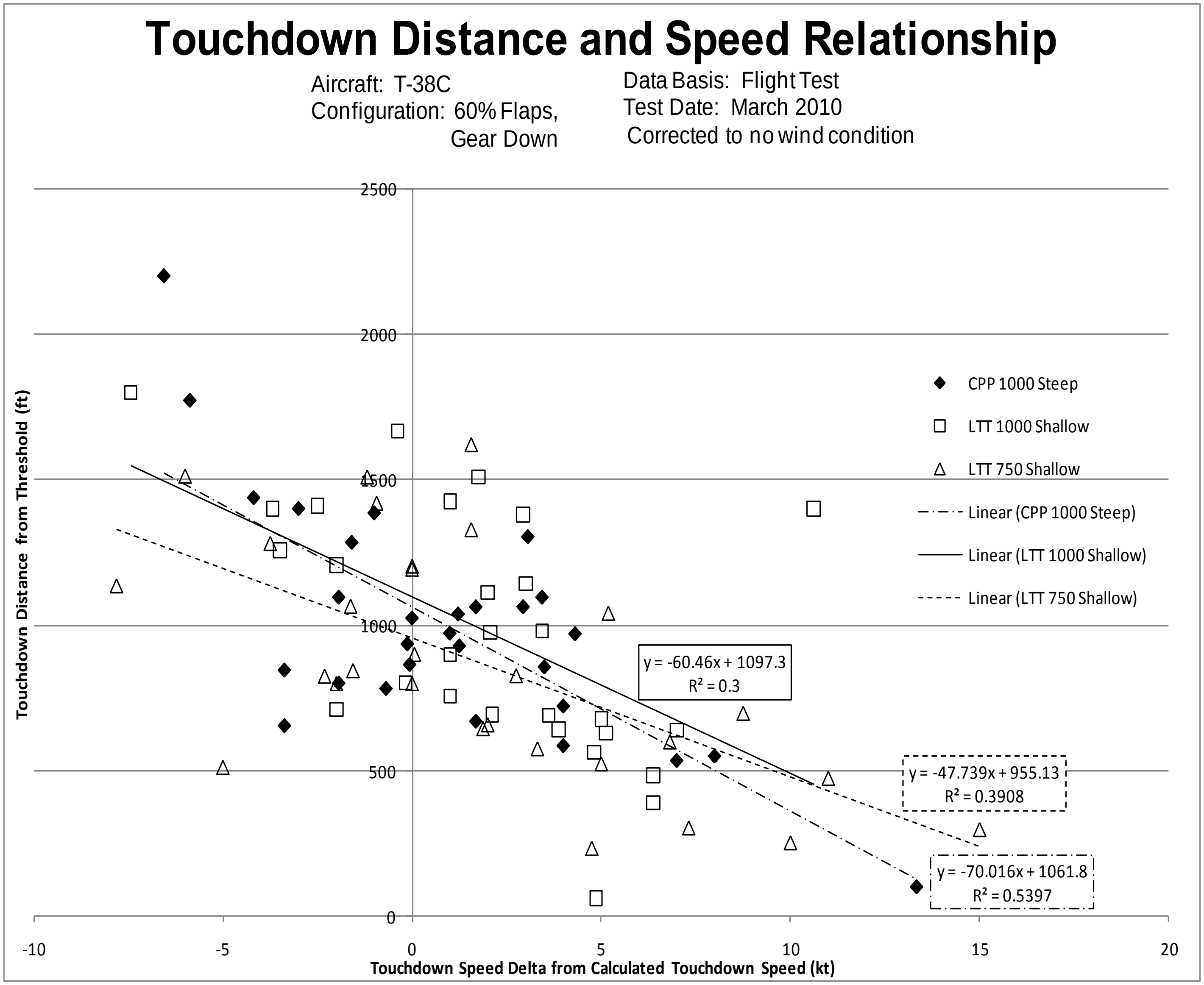

Figure A3 Correlation between Touchdown Distance and Touchdown Speed

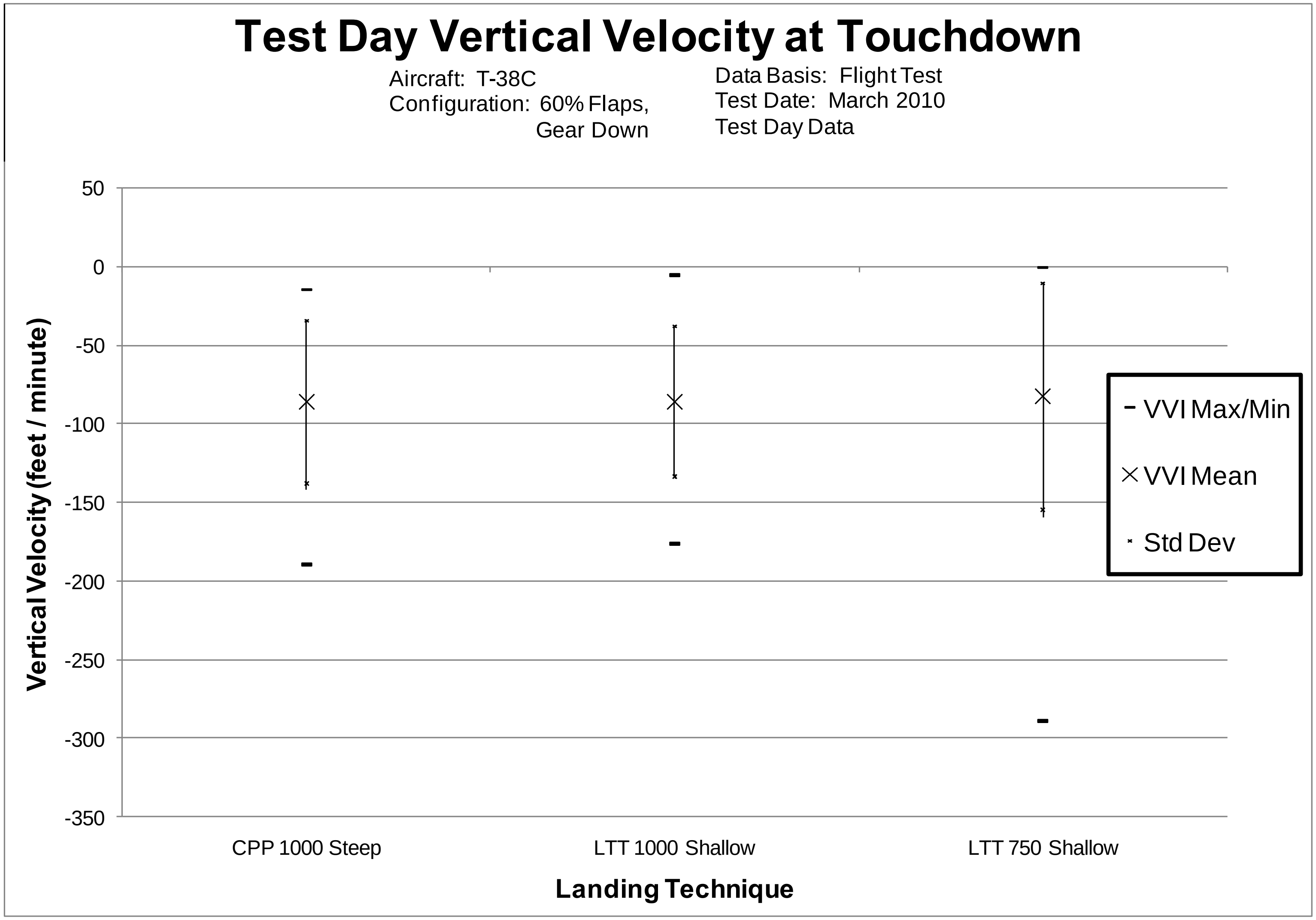

Figure A4 Vertical Velocity at Touchdown

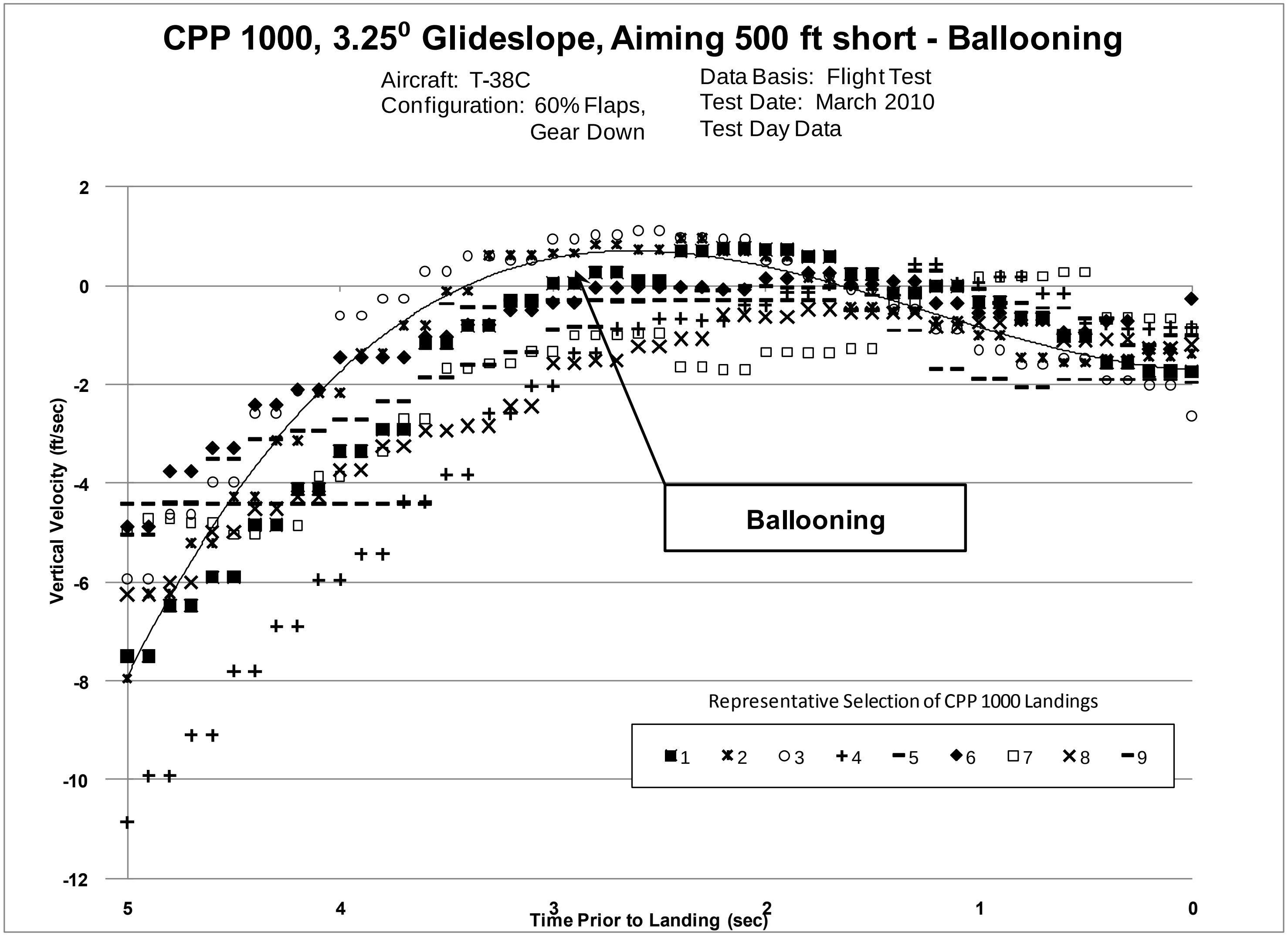

Figure A5 Vertical Velocity at Prior to Touchdown (CPP 1000 Steep)

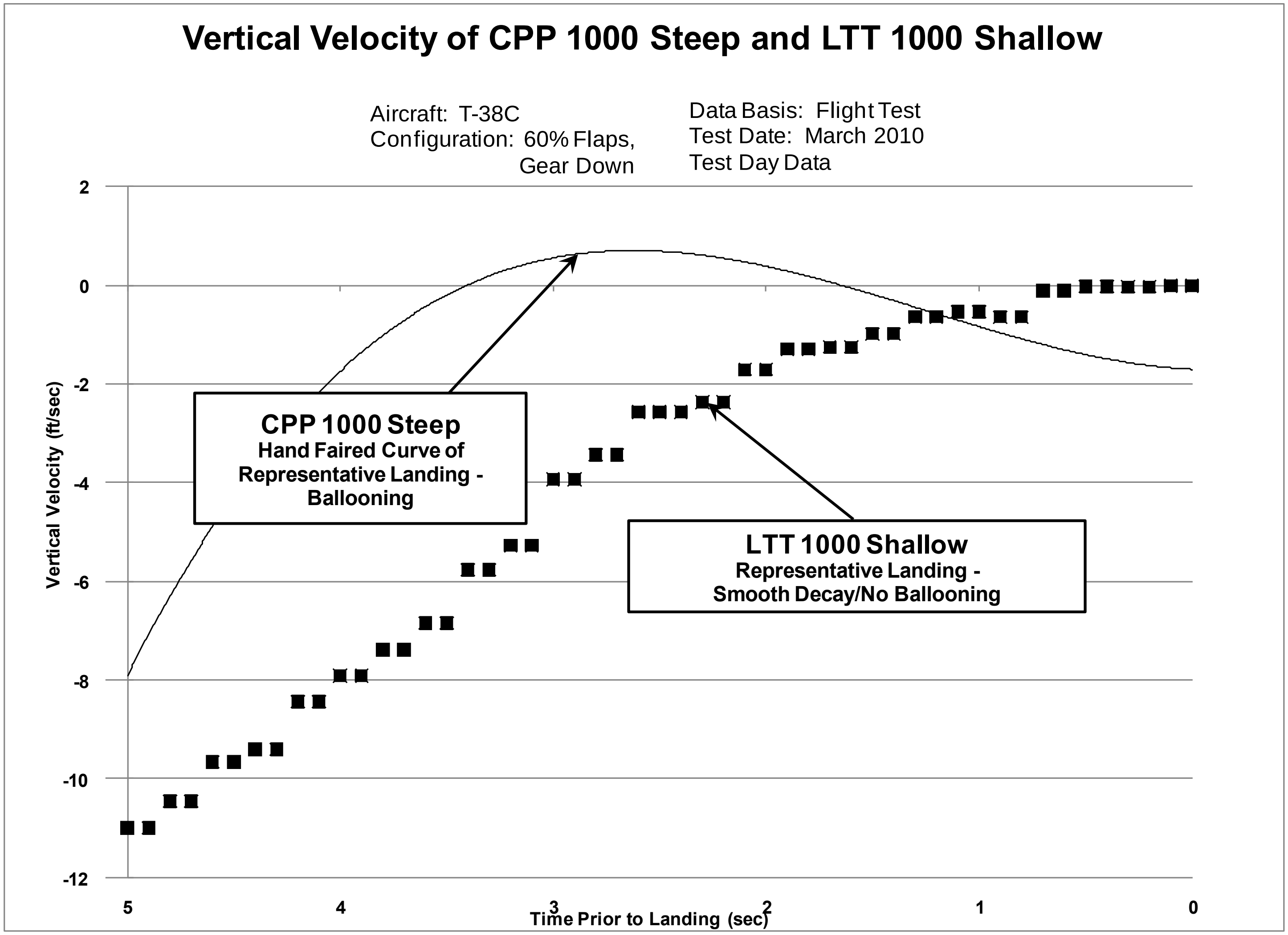

Figure A6 Vertical Velocity at Prior to Touchdown (CPP 1000 Steep, LTT 1000 Shallow)

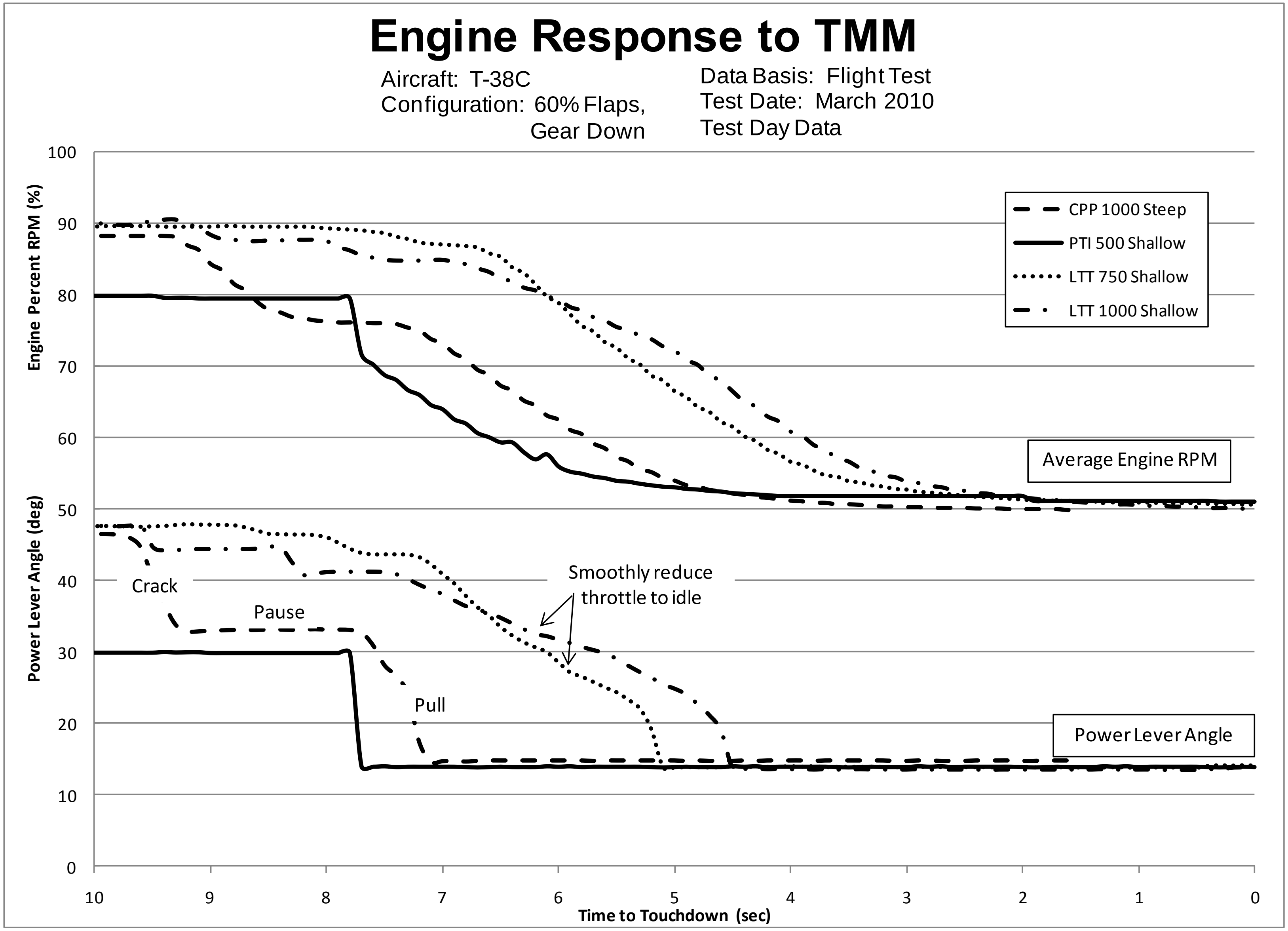

Figure A7 Engine Response to Various TMMs

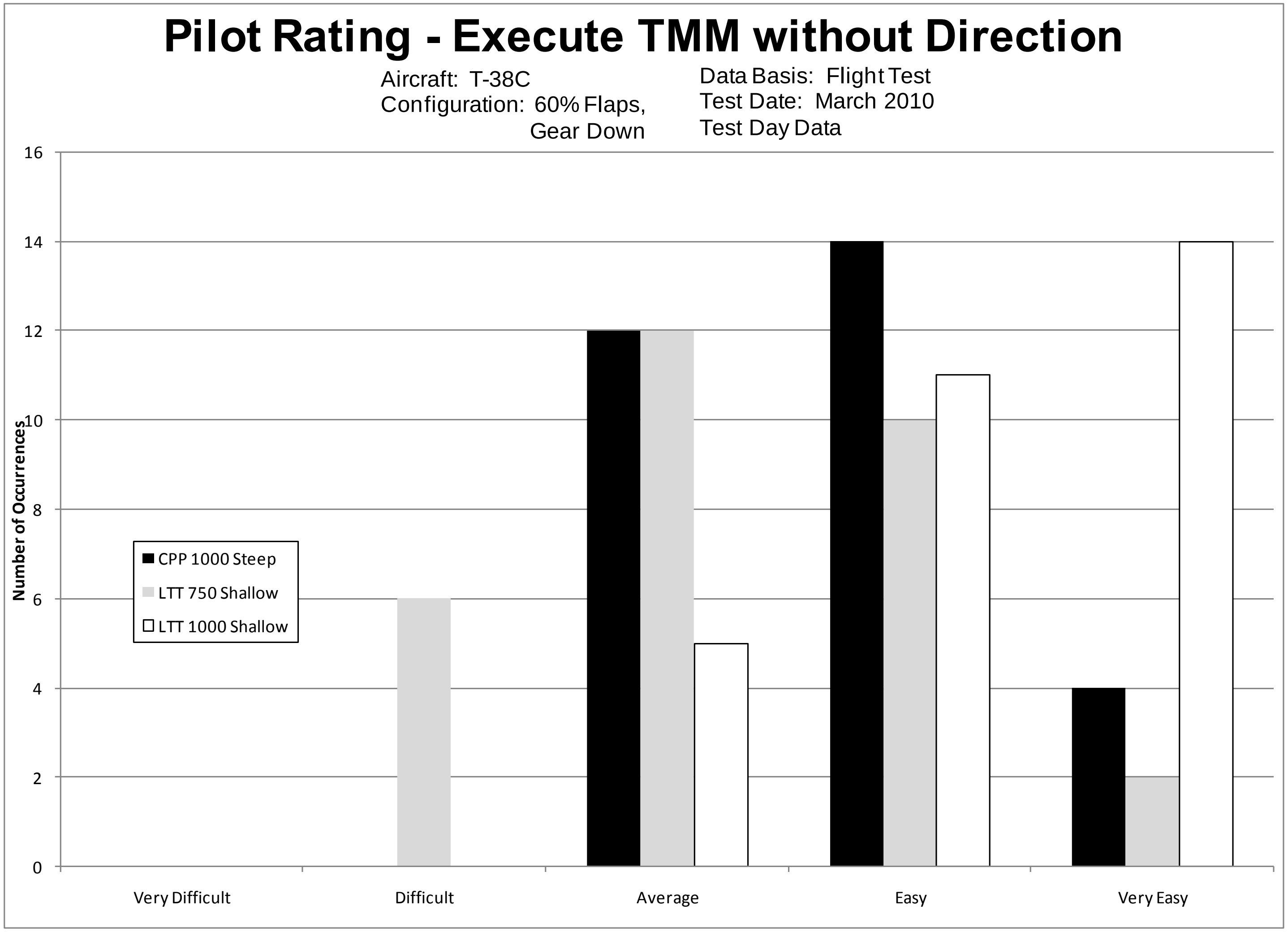

Figure A8 Pilot‟s Ability to Execute TMM at Proper Location without Direction

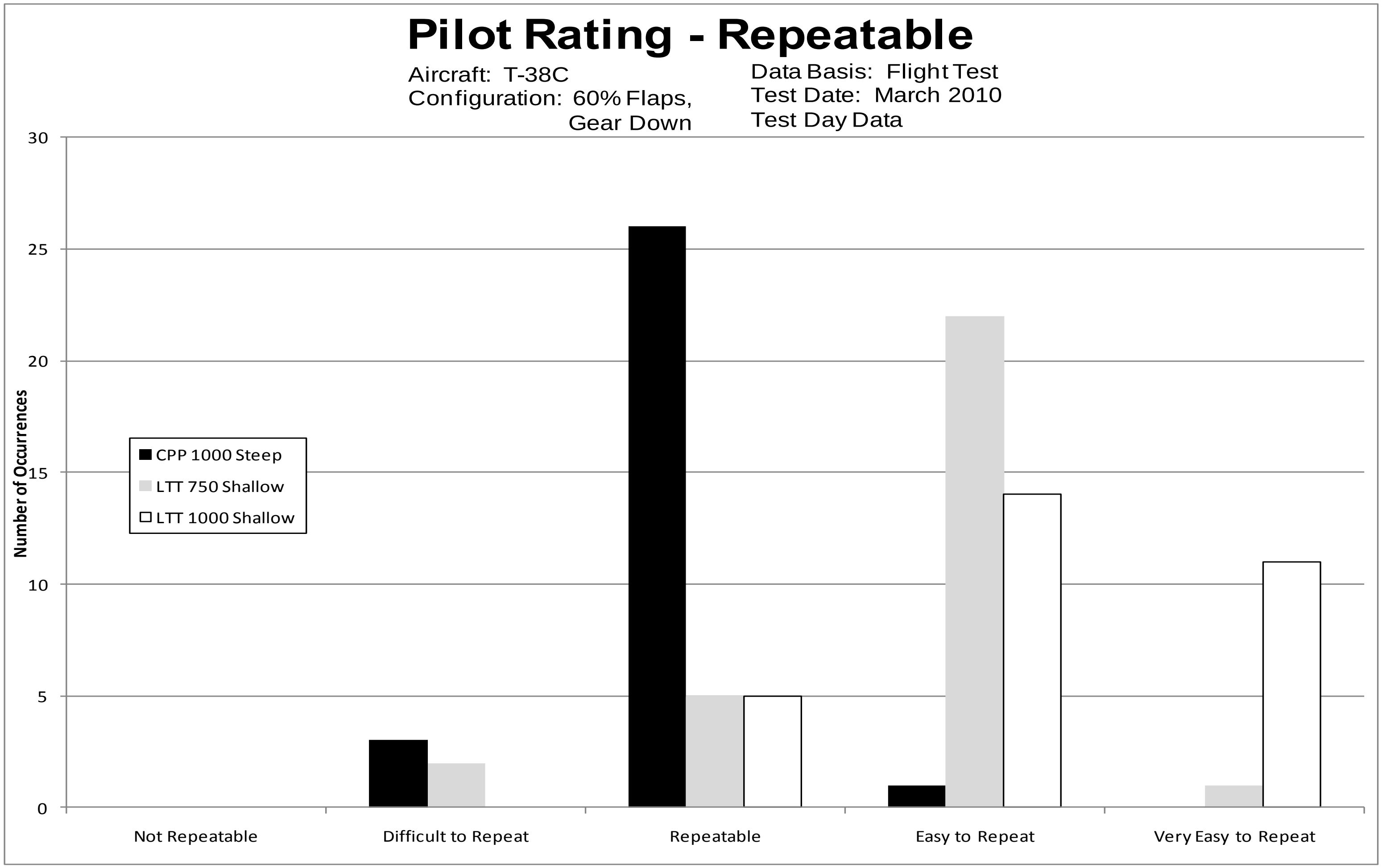

Figure A9 Pilot"s Assessment of Landing Repeatability

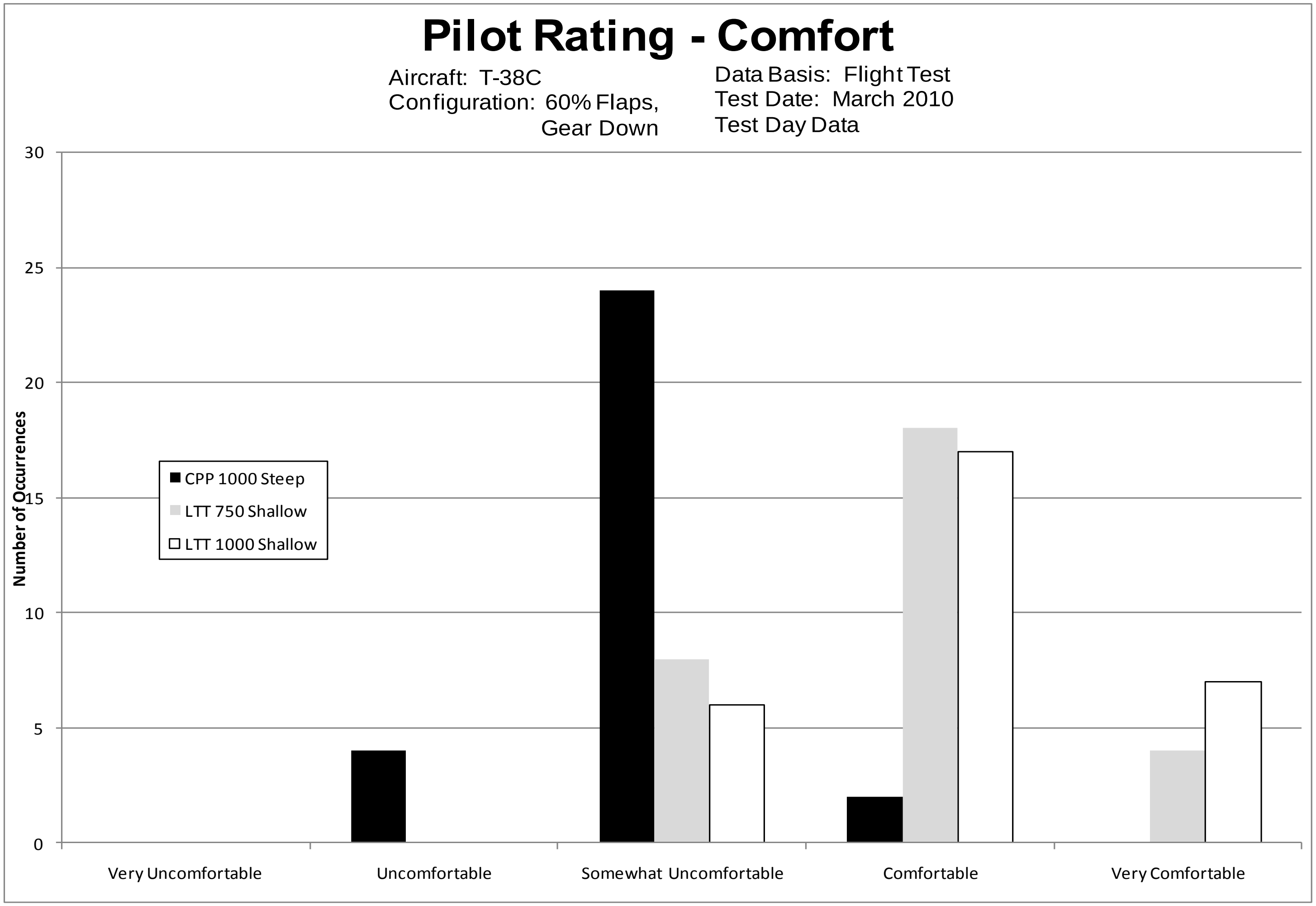

Figure A10 Pilot‟s Assessment of Landing Comfort

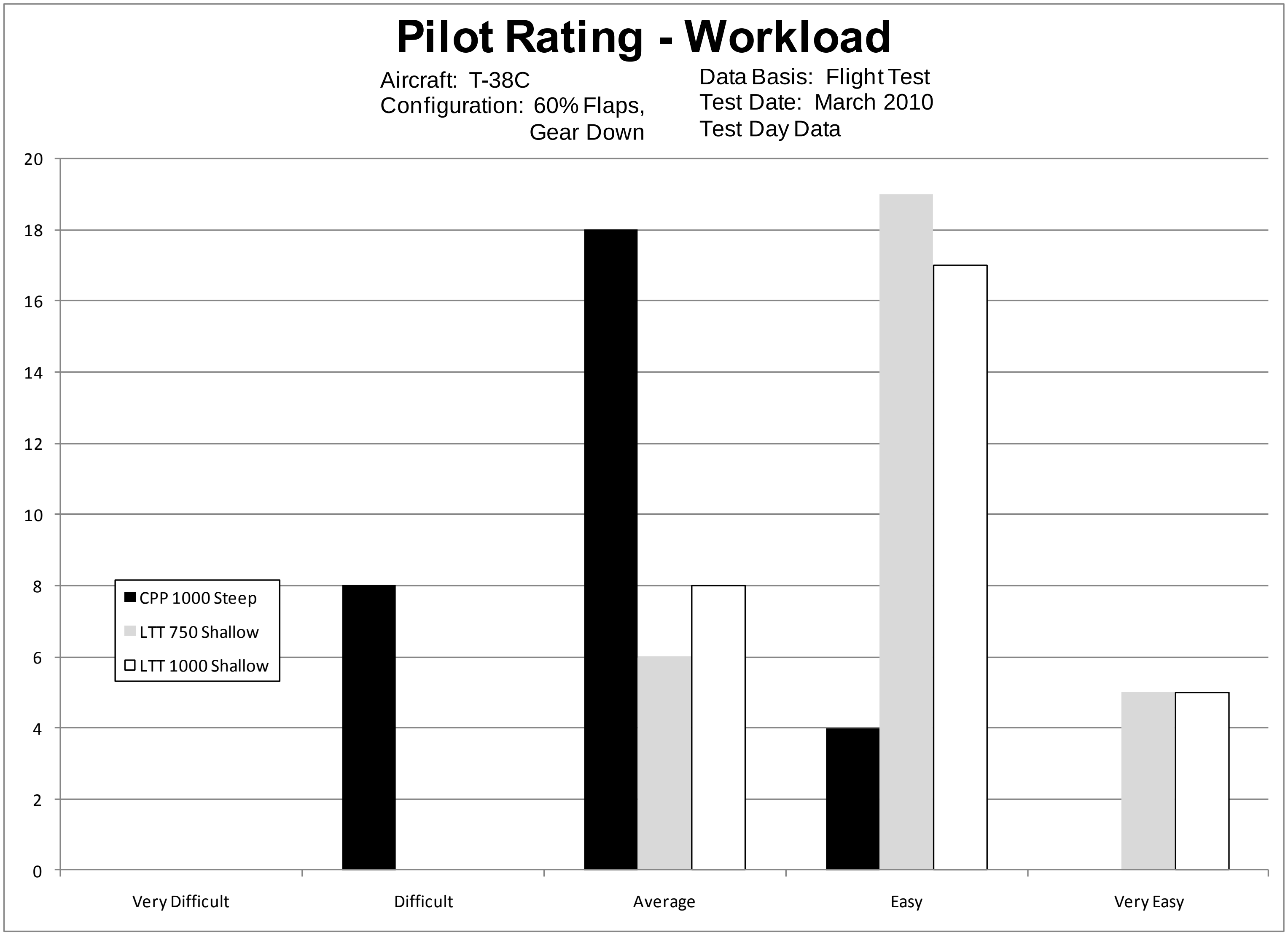

Figure A11 Pilot"s Assessment of Landing Workload

Figure A12 Pilot‟s Assessment of Landing Safety

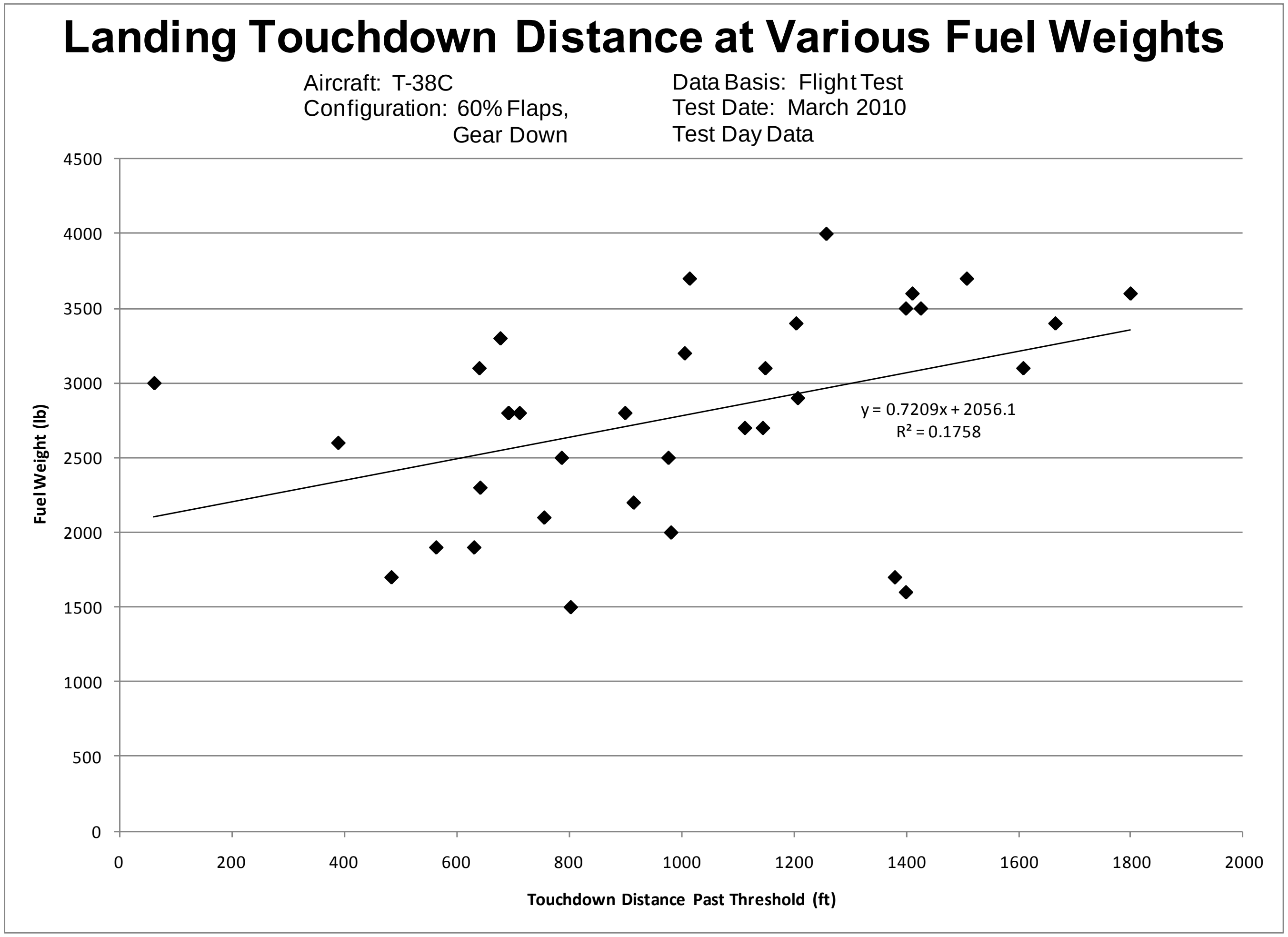

Figure A13 Correlation of Touchdown Distance and T-38C Fuel Weight

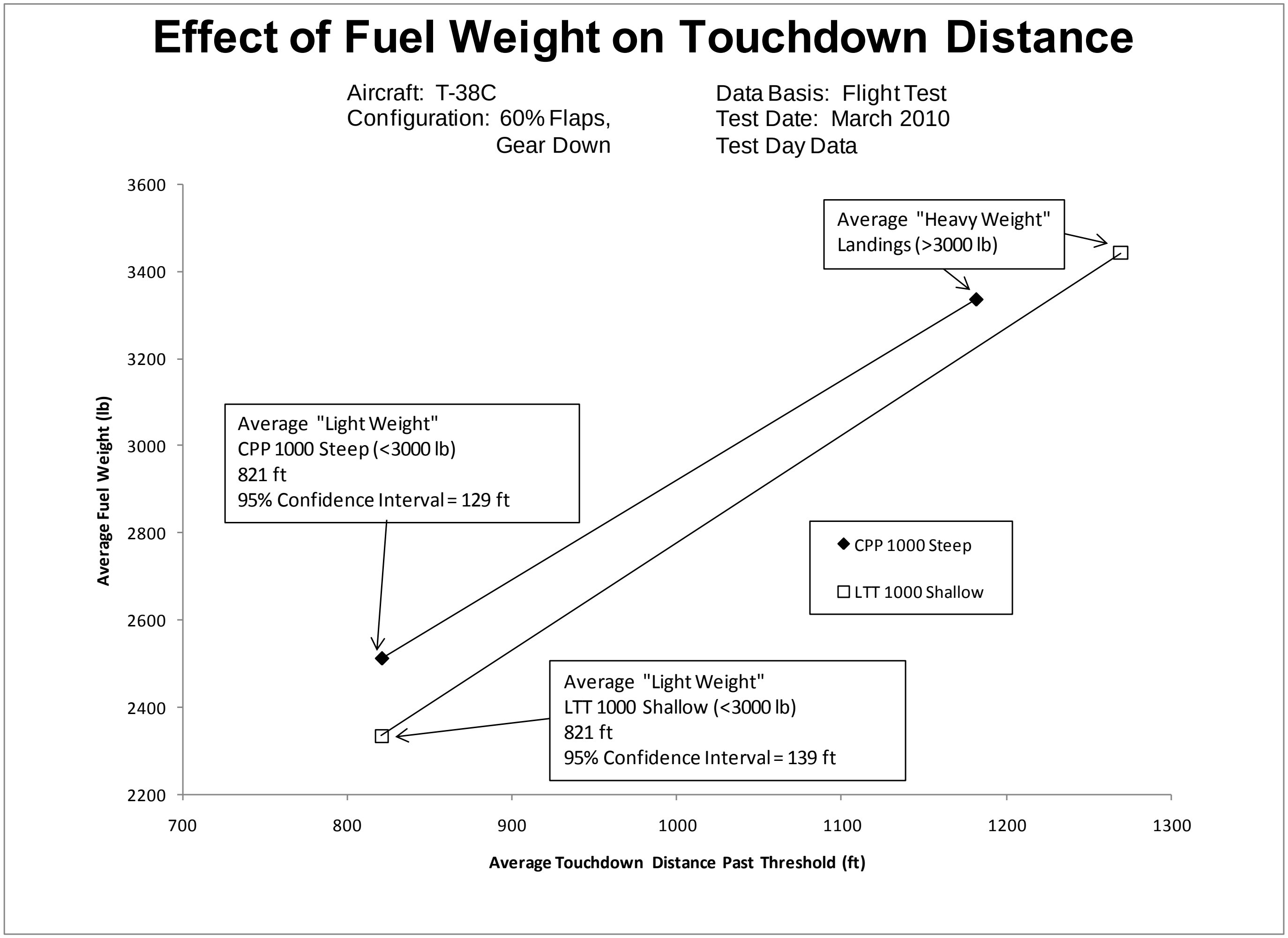

Figure A14 Relationship of Average Fuel Weights and Touchdown Distance

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APPENDIX B - SIMULATED EMERGENCY LANDINGS

Emergency landing configurations (no flap and simulated single engine) were evaluated on a limited basis during Phase B testing. The PID from AETC instructed that touchdown criteria for no flap and simulated single engine landings were:

- Touchdown location: 150 feet to 1,500 feet from the runway threshold
- Touchdown speed: -5 to +10 knots of desired touchdown speed

Table B1 summarizes the simulated emergency landing condition results. In all cases, touchdown speed and distance means were within AETC criteria. During the no flap and simulated single engine evaluations, the pilot adjusted the TMM as required to land safely.

Table B1 Simulated Emergency Landing Conditions

	Landing Technique	**Mean Touchdown Speed Delta (KCAS)**	**Mean Touchdown Distance (ft)**
Simulated Single Engine	Latch to the Threshold at 1000" Aim at Threshold 2.5° Glideslope	4.4	949
	Crack Pause Pull at 1000" Aim 500" Short 3.25° Glideslope	4.5	1151
	Latch to the Threshold at 750" Aim at Threshold 2.5° Glideslope	5.0	835
No Flaps	Latch to the Threshold at 1000" Aim at Threshold 2.5° Glideslope	5.4	726
	Crack Pause Pull at 1000" Aim 500" Short 3.25° Glideslope	2.8	959
	Latch to the Threshold at 750" Aim at Threshold 2.5° Glideslope	5.0	949

* Distance represents feet past the runway threshold where the main wheels touched down (wind corrected).

Crack Pause Pull 1000 Steep

The single-engine approach was made more difficult due to the multiple throttle changes on final. These changes in asymmetric thrust induced yaw rates which increased pilot workload during the maneuver. Due to the mechanization of the T-38 Flap-Slab Interconnect, the no-flap approach required more longitudinal stick travel than normal approaches to affect the same nose-up pitch change.

Latch to the Threshold 1000 and 750 Shallow

During simulated single-engine and no-flap approaches, the LTT TMM allowed a stable approach and flare from the start of the TMM through touchdown without any unsafe conditions experienced.

APPENDIX C - TOUCHDOWN DATA

Table C1 Touchdown Data Summary

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touchdown Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Martin Leim	LTT 1000 Shallow	197	5	2510	16	220	250	10-Mar	1427	1	5.5	-1.0	3500
Martin Leim	LTT 750 Shallow	197	5	2510	16	220	250	10-Mar	513	-5	0.75	-1.8	3300
Martin Leim	CPP 1000 Steep	197	5	2510	13	230	250	10-Mar	972	1	2.5	-0.4	3000
Martin Leim	LTT 1000 Shallow	197	5	2510	12	260	250	10-Mar	712	-2	5.5	-1.0	2800
Martin Leim	CPP 1000 Steep	197	5	2510	13	260	250	10-Mar	1024	0	3	0.0	2600
Martin Leim	LTT 750 Shallow	197	5	2510	15	280	250	10-Mar	1192	0	2.75	-0.1	2400
Martin Leim	LTT 750 Shallow	197	5	2510	17	280	250	10-Mar	1203	0	1	0.2	2300
Martin Leim	LTT 1000 Shallow	197	5	2510	20	270	250	10-Mar	756	1	3	-1.2	2100
Martin Leim	CPP 1000 Steep	197	5	2510	20	280	250	10-Mar	534	7	2.5	-2.1	2000
Martin Leim	LTT 750 Shallow No Flaps	197	5	2510	20	290	250	10-Mar	1188	4	5	-0.9	1800
Martin Leim	CPP 1000 Steep No Flaps	197	5	2510	18	270	250	10-Mar	557	-1	1	-0.5	1700

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch-down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Murphy Gunn-Golkin	LTT 1000 Shallow	197	0	2300	0	0	250	11-Mar	1400	-3.6875	4.5	-2.4	3500
Murphy Gunn-Golkin	LTT 750 Shallow	197	0	2300	0	0	250	11-Mar	800	-2	10.25	0.3	3300
Murphy Gunn-Golkin	CPP 1000 Steep	197	0	2300	0	0	250	11-Mar	200	4.25	0.75	-0.8	3200
Murphy Gunn-Golkin	CPP 1000 Steep	197	0	2300	0	0	250	11-Mar	1400	-3	1	-0.2	3000
Murphy Gunn-Golkin	LTT 1000 Shallow	197	0	2300	0	0	250	11-Mar	900	1	4.75	-0.8	2800
Murphy Gunn-Golkin	CPP 1000 Steep	197	0	2300	0	0	250	11-Mar	100	13.34	1	-1.9	2700
Murphy Gunn-Golkin	LTT 750 Shallow	197	0	2300	0	0	250	11-Mar	800	0	4.5	-0.5	2500

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch-down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Murphy Gunn-Golkin	LTT 750 Shallow	197	0	2300	0	0	250	11-Mar	900	0.0625	5	-1.4	2400
Murphy Gunn-Golkin	CPP 1000 Steep Single Engine		0	2300	0	0	250	11-Mar	800	-0.375	3.5	-1.1	2100
Murphy Gunn-Golkin	LTT 1000 Shallow Single Engine	197	0	2300	0	0	250	11-Mar	800	2.75	5	-0.5	1900
Murphy Gunn-Golkin	LTT 750 Shallow Single Engine	197	0	2300	0	0	250	11-Mar	900	4.28125	4	-0.1	1800
Murphy Gunn-Golkin	LTT 1000 Shallow No Flaps	197	0	2300	0	0	250	11-Mar	700	7.0625	1.5	-0.7	1600
Fann Gunn-Golkin	LTT 1000 Shallow	197	11	2290	11.5	20	070	11-Mar	1258	-3.5	5	-1.3	4000
Fann Gunn-Golkin	LTT 1000 Shallow	197	11	2290	12	40	070	11-Mar	1508	1.75	4.5	-1.7	3700

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch-down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Fann Gunn-Golkin	LTT 750 Shallow	197	11	2290	12	70	070	11-Mar	1619	1.5625	5.75	-2.5	3500
Fann Gunn-Golkin	CPP 1000 Steep	197	11	2290	12	50	070	11-Mar	1284	-1.59375		-2.2	3200
Fann Gunn-Golkin	CPP 1000 Steep	197	11	2290	10	30	070	11-Mar	864	-0.0625	2.5	-1.8	3000
Fann Gunn-Golkin	LTT 1000 Shallow	197	11	2290	7	80	070	11-Mar	1145	3	1.25	-2.9	2700
Fann Gunn-Golkin	CPP 1000 Steep	197	11	2290	6	10	070	11-Mar	1038	1.21875	1.5	-0.8	2600
Fann Gunn-Golkin	LTT 750 Shallow	197	11	2290	6	80	070	11-Mar	1041	5.1875	3	-1.9	2400
Fann Gunn-Golkin	LTT 750 Shallow	197	11	2290	6	40	070	11-Mar	646	1.875	2	-2.5	2200
Fann Gunn-Golkin	CPP 1000 Steep No Flaps	197	11	2290	13	60	070	11-Mar	1091	15.1875	1.5	-2.9	2100

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Fann Gunn-Golkin	LTT 1000 Shallow Single Engine	197	11	2290	12	6	070	11-Mar	751	4.1875	2	-2.2	1900
Martin Gunn-Golkin	LTT 750 Shallow	302	14	2350	3	350	070	11-Mar	659	2	4	-3.2	3400
Martin Gunn-Golkin	LTT 1000 Shallow	302	14	2350	5	340	070	11-Mar	678	5	2	-2.4	3300
Martin Gunn-Golkin	LTT 750 Shallow	302	14	2350	4	320	070	11-Mar	525	5	1.5	-2.6	3100
Martin Gunn-Golkin	LTT 750 Shallow	302	14	2350	0	0	070	11-Mar	1511	-6	3	-1.5	3000
Martin Gunn-Golkin	LTT 1000 Shallow	302	14	2350	4	360	070	11-Mar	1208	-2	4	-2.9	2900
Martin Gunn-Golkin	LTT 1000 Shallow	302	14	2350	4	60	070	11-Mar	1113	2	5	-1.8	2700
Martin Gunn-Golkin	CPP 1000 Steep	302	14	2350	4	310	070	11-Mar	721	4	5.75	-3.2	2500

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Martin Gunn-Golkin	CPP 1000 Steep	302	14	2350	4	30	070	11-Mar	549	8	1.75	-2.4	2300
Martin Gunn-Golkin	CPP 1000 Steep	302	14	2350	4	30	070	11-Mar	585	4	1.25	-2.7	2200
Martin Gunn-Golkin	LTT 750 Shallow Single Engine	302	14	2350	4	360	070	11-Mar	500	10	0.5	-1.9	2000
Martin Gunn-Golkin	CPP 1000 Steep Single Engine	302	14	2350	4	360	070	11-Mar	1538	2	2.5	-2.0	1900
Martin Gunn-Golkin	LTT 1000 Shallow Single Engine	302	14	2350	4	320	070	11-Mar	1092	10	2.75	-2.6	1800
Martin Gunn-Golkin	LTT 750 Shallow No Flaps	302	14	2350	4	330	070	11-Mar	1078	6	2.5	-2.0	1600
Fann Leim	LTT 750 Shallow	302	2	2350	0	0	250	12-Mar	1280	-3.75	3.5	-0.6	3600

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Fann Leim	CPP 1000 Steep	302	2	2350	0	0	250	12-Mar	845	-3.375	1.75	-1.7	3500
Fann Leim	LTT 750 Shallow	302	2	2350	0	0	250	12-Mar	236	4.75	2.5	-0.1	3300
Fann Leim	CPP 1000 Steep	302	2	2350	0	0	250	12-Mar	61	4.875	3	-1.8	3000
Fann Leim	LTT 1000 Shallow	302	2	2350	0	0	250	12-Mar	693	2.125	3	-1.1	2800
Fann Leim	LTT 1000 Shallow	302	2	2350	0	0	250	12-Mar	827	2.75	2.75	0.0	2700
Fann Leim	LTT 750 Shallow	302	2	2350	0	0	250	12-Mar	389	6.375	3	-0.9	2600
Fann Leim	LTT 1000 Shallow	302	2	2350	0	0	250	12-Mar	782	-0.6875	2.5	-2.6	2400
Fann Leim	CPP 1000 Steep	302	2	2350	0	0	250	12-Mar	669	1.6875	1	-0.9	2200
Fann Leim	CPP 1000 Steep No Flaps	302	2	2350	0	0	250	12-Mar	937	1	0.041666667	-1.1	2000

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Fann Leim	LTT 750 Shallow Single Engine	302	2	2350	0	0	250	12-Mar	1048	0.5	3.75	-0.8	1900
Fann Leim	LTT 1000 Shallow No Flaps	302	2	2350	0	0	250	12-Mar	456	8.9375	3	-1.1	1700
Murp hy Leim	LTT 750 Shallow	302	14	2350	0	0	250	12-Mar	1508	-1.1875	5	-0.5	3600
Murp hy Leim	CPP 1000 Steep	302	14	2350	0	0	250	12-Mar	1437	-4.1875	4	-1.0	3400
Murp hy Leim	CPP 1000 Steep	302	14	2350	0	0	250	12-Mar	1095	-1.9375	2	-1.0	3300
Murp hy Leim	LTT 750 Shallow	302	14	2350	0	0	250	12-Mar	1418	-0.9375	8.25	-0.6	3100
Murp hy Leim	LTT 750 Shallow	302	14	2350	0	0	250	12-Mar	1328	1.5625	3.5	-0.4	3000
Murp hy Leim	LTT 1000 Shallow	302	14	2350	0	0	250	12-Mar	692	3.625	3.75	-1.0	2800
Murp hy Leim	CPP 1000 Steep	302	14	2350	0	0	250	12-Mar	1062	1.6875	2	-0.3	2700

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Murphy Leim	LTT 1000 Shallow	302	14	2350	0	0	250	12-Mar	977	2.0625	3	-1.3	2500
Murphy Leim	LTT 1000 Shallow	302	14	2350	0	0	250	12-Mar	642	3.875	2.5	0.7	2300
Murphy Leim	LTT 1000 Shallow Single Engine	302	14	2350	0	0	250	12-Mar	1154	0.5625	6.25	-0.7	2200
Murphy Leim	LTT 750 Shallow Single Engine	302	14	2350	0	0	250	12-Mar	896	5.25	6.5	-0.5	2000
Murphy Leim	CPP 1000 Steep Single Engine	302	14	2350	0	0	250	12-Mar	794	0.625	2.125	-0.9	1900
Murphy Leim	CPP 1000 Steep No Flaps	302	14	2350	0	0	250	12-Mar	1270	-0.125	2.625	-0.7	3200

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Murphy Leim	LTT 1000 Shallow No Flaps	302	14	2350	0	0	250	12-Mar	549	3.5625	2	-1.1	3100
Bippert Leim	LTT 1000 Shallow	302	18	2420	7	240	250	12-Mar	1412	-2.5	4.3125	-0.5	3600
Bippert Leim	LTT 1000 Shallow	302	18	2420	7	240	250	12-Mar	1666	-0.375	6.5	-1.5	3400
Bippert Leim	LTT 750 Shallow	302	18	2420	12	240	250	12-Mar	306	7.3125	3	-2.0	3200
Bippert Leim	CPP 1000 Steep	302	18	2420	10	220	250	12-Mar	1062	2.9375	3.5	-0.9	3300
Bippert Leim	LTT 1000 Shallow	302	18	2420	11	260	250	12-Mar	640	7	3.5	-1.0	3100
Bippert	LTT 750 Shallow	302	18	2420	9	240	250	12-Mar	255	10	2.25	-2.2	2900
Bippert Leim	CPP 1000 Steep	302	18	2420	9	290	250	12-Mar	654	-3.375	2.25	-0.9	2800
Bippert Leim	LTT 750 Shallow	302	18	2420	10	230	250	12-Mar	698	8.75	2.5	-0.2	2600

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Bippert Leim	CPP 1000 Steep	302	18	2420	11	240	250	12-Mar	970	4.3125	4	-1.2	2400
Bippert Gunn-Golkin	CPP 1000 Steep	197	2	2220	0	0	250	15-Mar	1772	-5.875	3.625	-0.7	3500
Bippert Gunn-Golkin	CPP 1000 Steep	197	2	2220	0	0	250	15-Mar	2200	-6.5625	4	-1.8	3400
Bippert Gunn-Golkin	LTT 750 Shallow	197	2	2220	0	0	250	15-Mar	826	-2.3125	3.25	-0.6	3300
Bippert Gunn-Golkin	CPP 1000 Steep	197	2	2220	0	0	250	15-Mar	1385	-1	2	-0.5	3000
Bippert Gunn-Golkin	LTT 750 Shallow	197	2	2220	0	0	250	15-Mar	300	15	2.5	-2.3	2800
Bippert Gunn-Golkin	LTT 750 Shallow	197	2	2220	5	340	250	15-Mar	475	11	1	-4.8	2600
Bippert Gunn-Golkin	LTT 1000 Shallow	197	2	2220	0	0	250	15-Mar	787	3.9375	4.5	-0.5	2500

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Bippert Gunn-Golkin	LTT 1000 Shallow No Flaps	197	2	2220	0	0	250	15-Mar	1200	2	4.75	-0.2	3800
Bippert Gunn-Golkin	LTT 750 Shallow No Flaps	197	2	2220	0	0	250	15-Mar	582	5.0625	2	-0.8	3600
Bippert Gunn-Golkin	CPP 1000 Steep No Flaps	197	2	2220	0	0	250	15-Mar	1100	2	2.5	-0.4	3400
Bippert Gunn-Golkin	CPP 1000 Steep Single Engine	197	2	2220	0	0	250	15-Mar	1121	11	3.25	-0.1	1800
Bippert Gunn-Golkin	LTT 1000 Shallow	197	2	2220	0	0	250	15-Mar	1400	10.625	9.75	-1.6	1600
Bippert Gunn-Golkin	LTT 1000 Shallow	197	2	2220	3	330	250	15-Mar	803	-0.1875	3.5	-0.8	1500
Fann Gunn-Golkin	LTT 750 Shallow	197	3	2310	5	70	250	17-Mar	1065	-1.625	2.5	-0.6	2800

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Fann Gunn-Golkin	CPP 1000 Steep	197	3	2310	0	0	250	17-Mar	649	3.1875	4.5	-1.4	2700
Fann Gunn-Golkin	LTT 750 Shallow	197	3	2310	0	0	250	17-Mar	844	-1.5625	2.5	-1.2	2600
Fann Gunn-Golkin	CPP 1000 Steep	197	3	2310	5	340	250	17-Mar	800	-1.9375	4	-0.5	2400
Fann Gunn-Golkin	LTT 1000 Shallow	197	3	2310	5	310	250	17-Mar	915	5.75	5	-1.0	2200
Fann Gunn-Golkin	LTT 750 Shallow	197	3	2310	5	340	250	17-Mar	600	6.8125	1.5	-0.1	2100
Fann Gunn-Golkin	LTT 1000 Shallow	197	3	2310	5	70	250	17-Mar	631	5.125	2.5	-0.1	1900
Fann Gunn-Golkin	CPP 1000 Steep	197	3	2310	4	360	250	17-Mar	1095	3.4375	3.5	-2.0	1800
Fann Gunn-Golkin	LTT 1000 Shallow	197	3	2310	5	70	250	17-Mar	484	6.375	2.5	-0.5	1700
Bippert Leim	CPP 1000 Steep	197	22	2210	4	30	070	17-Mar	856	3.5	1.25	-0.7	2800

Table C1 Touchdown Conditions and Data Continued

Pilot FTE	Landing Technique	Aircraft Tail Number	Temp-erature (deg C)	Pressure Altitude (ft)	Wind Speed	Wind Direction	Run way	Date	Touch down Distance (ft)	Touchdown Speed Delta (kt)	Height over Threshold (ft)	Vertical Velocity at Touchdown (ft/min)	Fuel Weight (lb)
Bippert Leim	LTT 750 Shallow	197	22	2210	4	360	070	17-Mar	989	1.9375	1.5	-2.4	2700
Bippert Leim	CPP 1000 Steep	197	22	2210	4	310	070	17-Mar	928	1.25	2	-3.1	2500
Bippert Leim	LTT 750 Shallow	197	22	2210	3	30	070	17-Mar	577	3.3125	3.75	-2.1	2300
Bippert Leim	LTT 750 Shallow	197	22	2210	3	120	070	17-Mar	1135	-7.8125	1.75	-3.0	2200
Bippert Leim	LTT 1000 Shallow	197	22	2210	3	160	070	17-Mar	982	3.4375	4.75	-2.4	2000
Bippert Leim	LTT 1000 Shallow	197	22	2210	3	160	070	17-Mar	563	4.8125	3.75	-2.7	1900
Bippert Leim	LTT 1000 Shallow	197	22	2210	3	150	070	17-Mar	2.9375	2.9375	4.5	-2.3	1700
Bippert Leim	CPP 1000 Steep	197	22	2210	3	150	070	17-Mar	3.0625	3.0625	1.5	-2.0	1600

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APPENDIX D - HEIGHT OVER THRESHOLD DETERMINATION

Aircraft height over threshold (HOT) was determined through the comparison of a "calibration" photo with a photo of the aircraft as it passed over the threshold (figure D1). Accuracy was within ±3 inches, based on the zoom and shutter rate of the digital images used for the measurement. Before each flight, a digital video camera would be placed in the End-of-Runway (EOR) area, directly in line with the threshold. This camera would remain stationary for the duration of the test sortie. Next, the camera would record a picture of the calibration pole situated at the center of the runway threshold. During the sortie, this camera would record the test aircraft at a rate of 30 Hz as it crossed the runway threshold. After each sortie, the calibration image would be used to mark a piece of paper overlaid on the viewing monitor. Each landing video would be paused with the aircraft over the threshold and the HOT would be measured, referencing the paper overlay. Because the aircraft was sometimes not photographed directly over the threshold, the team member would visually interpolate and pick the closest 0.25 foot increment, thus resulting in a ±3 inches uncertainty. The figures below show an example calibration and flight photo used in HOT assessment (figure D2).

Figure D1 Calibration Pole and T-38C Crossing Threshold

Figure D2 Comparison to Determine Threshold Crossing Height

APPENDIX E - LESSONS LEARNED

Several lessons were learned throughout the Talon Spot Test Management Project. A significant lesson learned was that more of an effort should have been made during the test planning process to prioritize testing at operationally representative conditions, in this case lower fuel weights. Before the test flights, it was assumed that all landing distances would be relatively unaffected by landing weight. Thus, the desire to carry extra fuel for contingencies (pattern delays, multiple botched test points, etc) and the desire to perform several emergency procedure landings per sortie, drove the plan to begin testing as quickly as possible on each test sortie, thus saving as much fuel as possible for the unexpected. This, in conjunction with the requirement that all simulated EP patterns be flown below 2500 pounds of gas (no-flap patterns driven by regulation, simulated single engine patterns driven by Safety Review Board risk mitigation) caused over one third of all landings to occur with over 3000 pounds of gas on board. Landings at these heavy weights are relatively rare in the T-38 pilot-training environment (exceptions being pattern-only sorties and heavy-weight simulated single-engine touch-and-goes). Testing at an out-base also imposed fuel restrictions which were unavoidable. However, given the significant connection between fuel weight and landing distance revealed during this test, future testing should place more emphasis on testing at fuel weights below the fuel weight of 3000 pounds, to produce results relevant to those landings most commonly experienced during pilot-training operations.

Simplicity should never be discounted. Sometimes the simplest solutions are truly the best ones. The most accurate measurements of the entire test were obtained with a $10 calibration pole built by students in the TPS parking lot, digital photographs, a pencil and paper. Handheld data collection, to include observations out the window during landings, were consistently within ±1 KIAS and ±100 feet of the GPS/DAS provided touchdown speed and landing distance, respectively. In fact, much of this test program could have been conducted with no instrumentation at all on the aircraft, with only a slight modification to the test objectives. Never overlook the simple solutions in test.

Take advantage of simulators and check-out flights if available. Valuable experience gained from these sources can help vector your test prior to the first official “test flight”. Although the limitations of simulators are well known, they should not be discounted entirely, even in landing testing. Even though there was no way our simulator could replicate ground rush or other phenomena experienced in a landing, it was instrumental in the preparation of our flight test procedures, to include pattern operations and in-flight questionnaires. Flying the patterns in the simulator allowed us to understand more fully how long each pattern would take, and to realize when certain questions were too long or complicated to be effectively utilized in flight. Test card formats were refined during practice simulator sessions. In addition, the checkout flights allow the pilots the opportunity to go though some of the test procedures themselves, although competing interests (C-model versus A/B model and EP pattern checkout) did reduce their usefulness. A dedicated practice test sortie with the FTEs would have been optimum, although it is recognized that this will rarely be available in most tests.

The test strategy executed involved eliminating eight of fourteen possible landing technique combinations based on a low-fidelity simulator and a scattering of landings (1-2 landings per combination, usually by only one or two pilots) between all four pilots. These sorties were operated under the prevailing conditions and involved no true data collection, beyond pilot comments. Due to the low sortie count available, this was unavoidable. Thus, the test team accepted the significant technical risk that a “good” technique would be eliminated due to circumstances not related to its merits, in exchange for a relatively low sortie count during the test. This risk was again accepted in Phase A, which was reduced from four to two sorties during test planning for the same reason. Although there will often be times where this type of situation is unavoidable, it must be acknowledged and mitigated as much as possible at the beginning of the test. In this case, the twelve sortie flight restriction and the desire to achieve results of a high statistical confidence required the test team to accept this risk. Follow-on teams should be cognizant of these trade-offs and make the best decision, weighing the consequences at each step. Once again, pilot comments were the deciding factor at all stages of this test.

The make-up of the test team was non-standard in that it consisted of four pilots and only two FTEs, as opposed to the usual even breakdown between the two. Due to the nature of our test, which relied heavily on the diversity and number of pilots involved, this was appropriate. Always evaluate the test approach and requirements to ensure that the appropriate test team can be assembled. Executing this test with only three pilots would have been significantly more difficult and would have provided lower quality results than conducting it as we did, with four pilots.

APPENDIX F - LIST OF ABBREVIATIONS AND SYMBOLS

AETC	Air Education and Training Command
AFB	Air Force Base
AFFTC	Air Force Flight Test Center
AGL	Above Ground Level
CI	Confidence Interval
CPP	Crack-Pause-Pull
CTI	Crack then Idle
DAS	Data Acquisition System
deg	Degree
FAS	Final Approach Speed
ft	feet
FTE	Flight Test Engineer
FPM	Flight Path Marker
GPS	Global Positioning System
HOT	Height Over Threshold
HUD	Heads Up Display
IRIG	Inter-Range Instrumentation Group
LTT	Latch-to-the-Threshold
MFD	Multiple Flight Displays
PID	Program Introduction Document
PTI	Pull-to-Idle
RPM	Rotations Per Minute
std dev	Standard Deviation
SUPT	Specialized Undergraduate Pilot Training
TMM	Throttle Modulation Method
TPS	Test Pilot School
TW	Test Wing
USAF	United States Air Force
VVI	Vertical Velocity Indicator

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